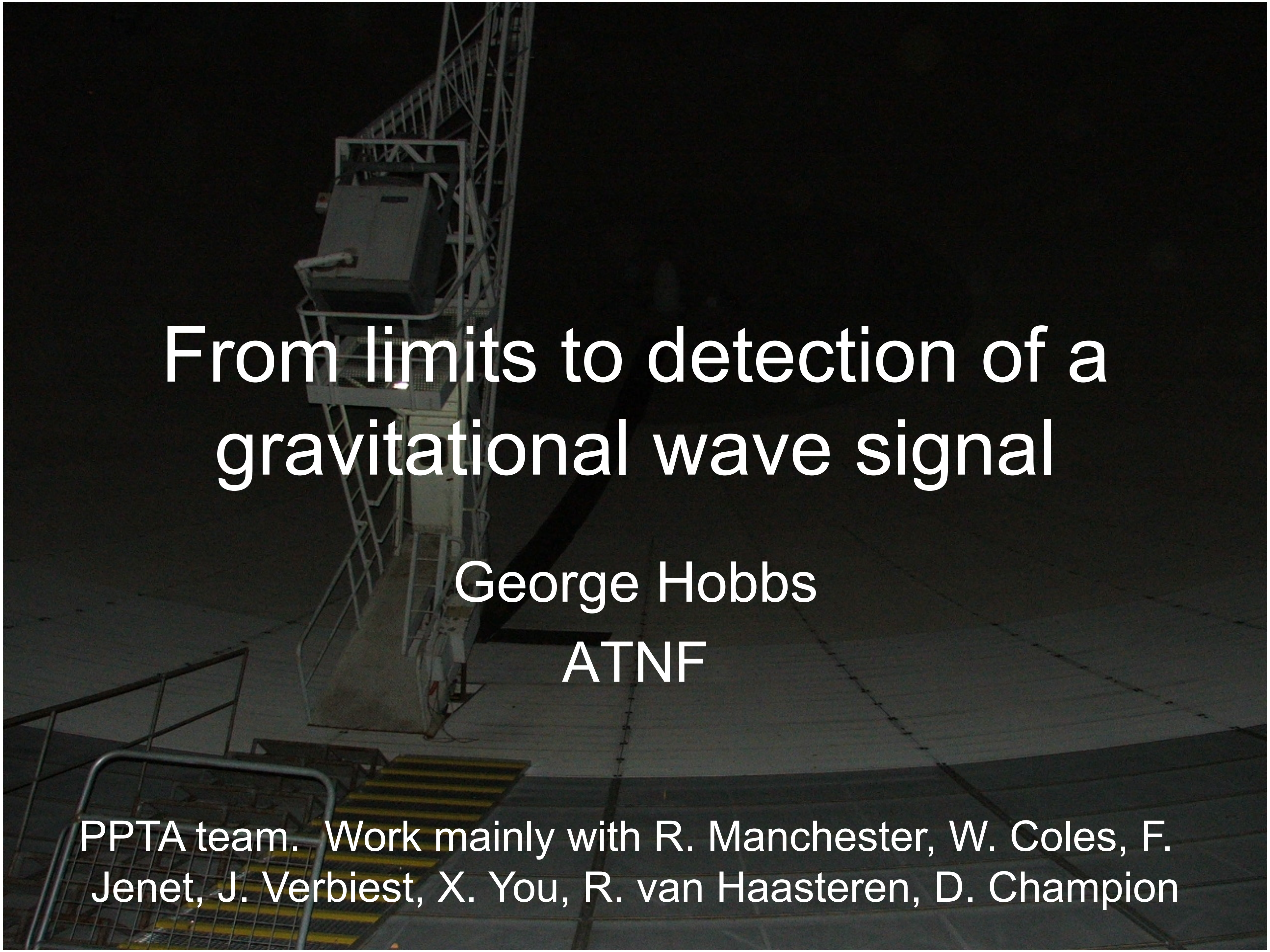

From limits to detection of a gravitational wave signal

George Hobbs

ATNF

PPTA team. Work mainly with R. Manchester, W. Coles, F. Jenet, J. Verbiest, X. You, R. van Haasteren, D. Champion

What we want to say …

- Detected a gravitational wave background created from supermassive black hole binary systems, with strain amplitude h_c(f).
- The gravitational waves detected are (not) consistent with the predictions of general relativity

What we can say …

- We can limit any background described by a strain spectrum: $h(f) = A(f/f_{1yr})^{-2/3}$ giving $A < 1.1 \times 10^{-14}$.
- This result can constrain the merger rate of supermassive binary black holes (see Jenet et al. 2006).

Purpose of talk …

- Highlight what we need to do in order to make a detection.
- Do we have a chance?

- *Want to give an overview of the problems, not their final solution. Highlight that lots of science can be achieved along the way. (See talk following by Bill Coles)*

Summary for galaxy community

- We need help to obtain a good estimate of the properties of the GW background from a population of massive black hole binaries.
- Black hole mass function - merger rate - GW background (not a black box!)
- We can already place limits on the amplitude of any such background

Summary for GW community

- We have an excellent chance of making a *direct* detection of low frequency GW signals within the next 5->10 years *(assuming that the theoretical models are correct).*
- When making models - consider the low-frequency band.

Summary for pulsar community

- We must lower our rms timing residuals towards the 100ns goal.
- There are many possible ways to do this.

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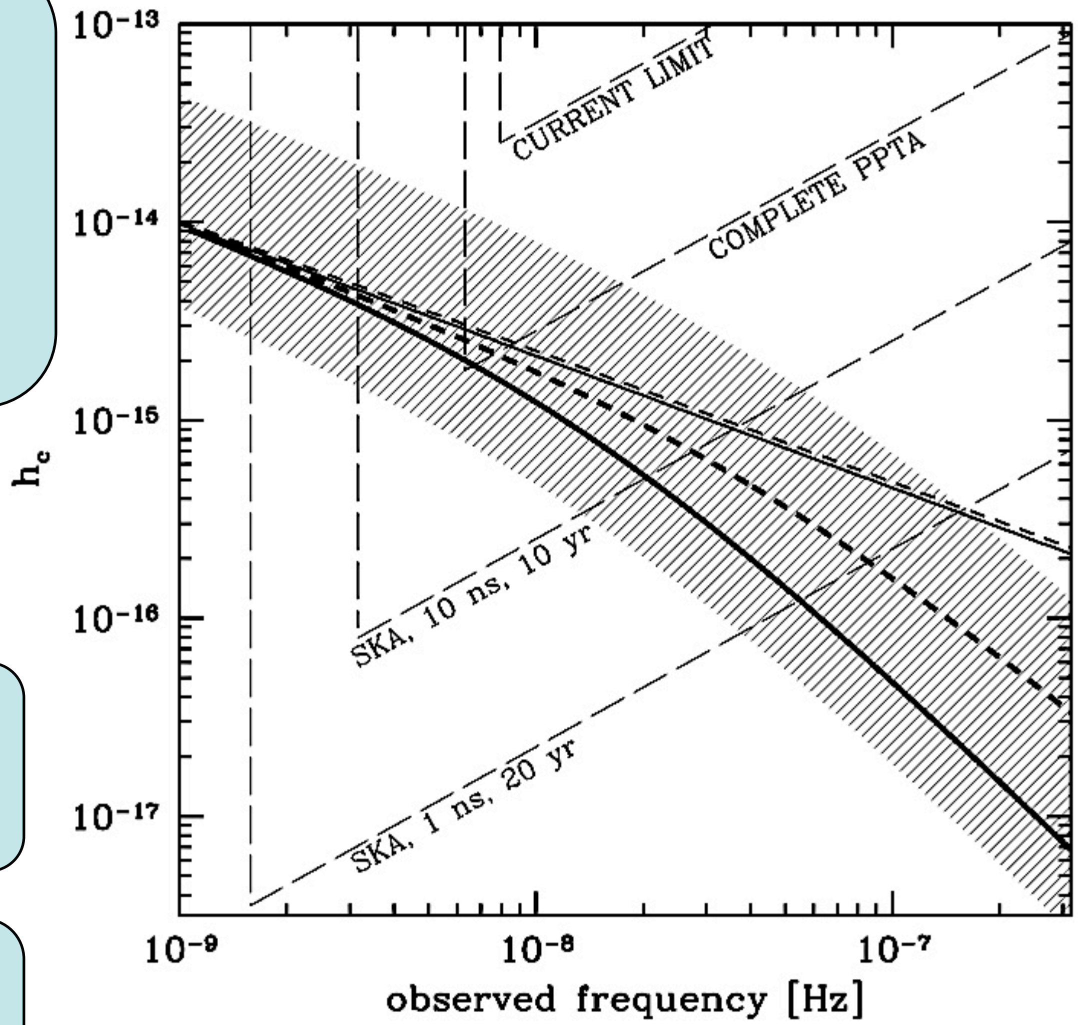
Gravitational wave detection

- Do backgrounds exist?
- What forms a GW background?

Sesana et al. 2008 (on astro-ph)



Spectral exponent ~ -2/3

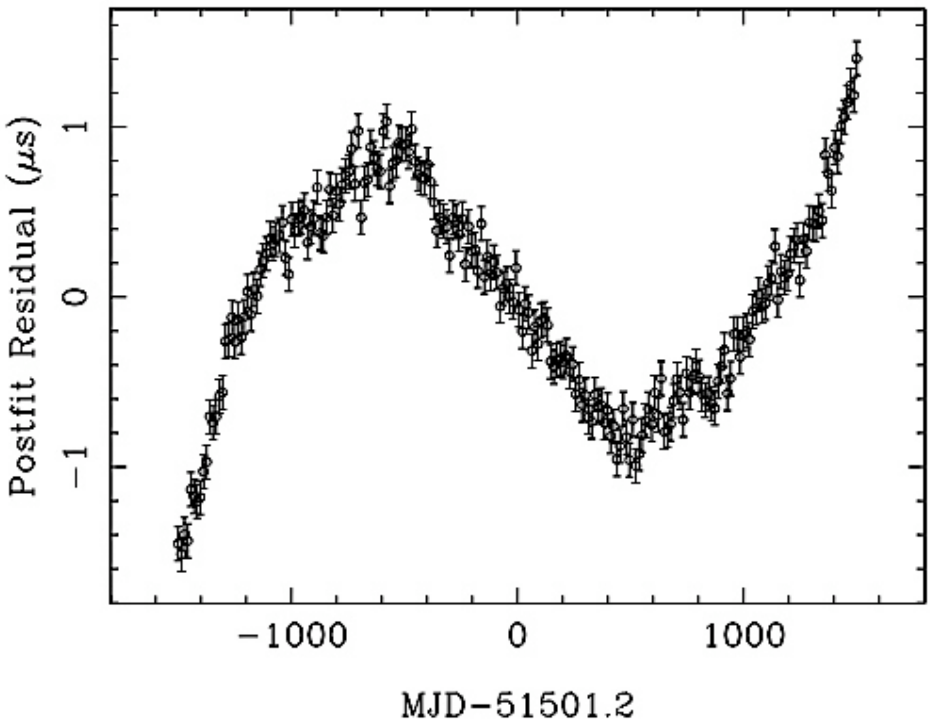
$5\times10^{-16} < h(f=10^{-8}\text{Hz}) < 8\times10^{-15}$

GW background dominated by massive ($M > 10^8$ Mo) and nearby ($z < 2$) binary systems

Gravitational wave detection

What would our timing residuals look like?

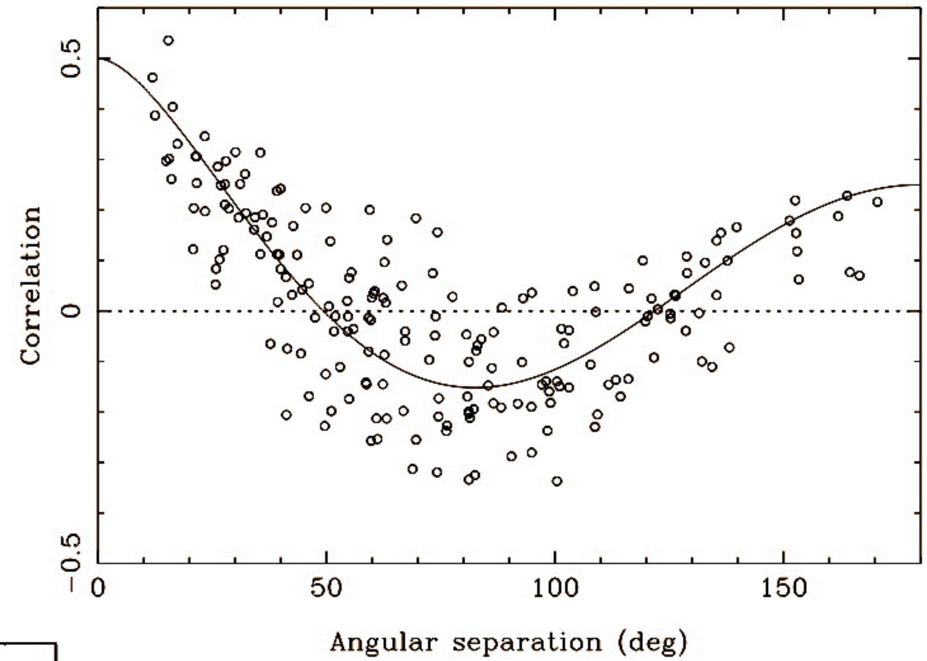
Timing residuals induced by GW background with $A = 10^{-14}$

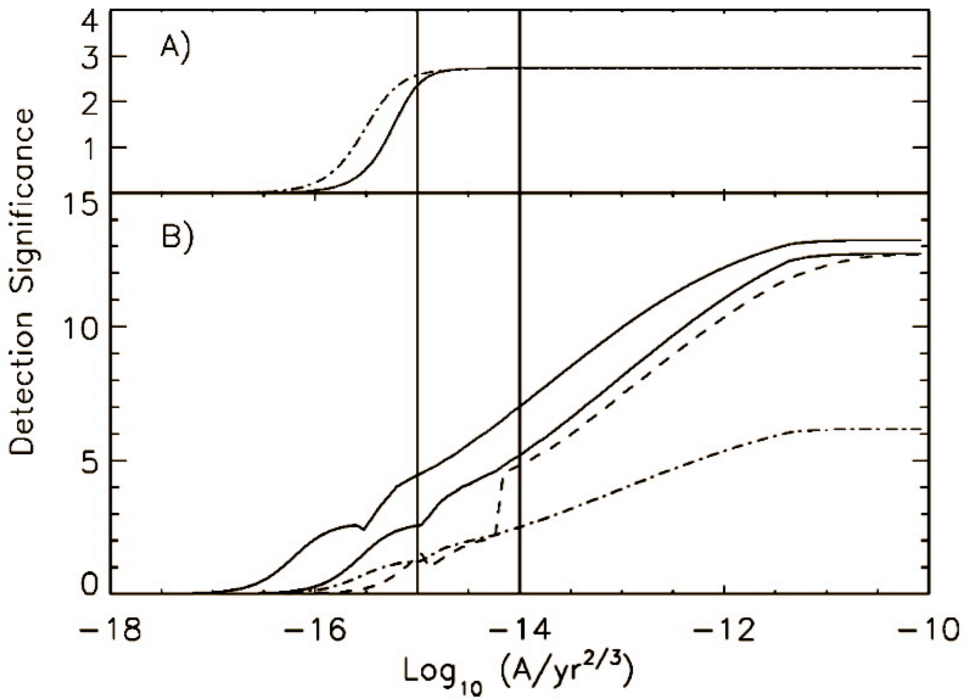


See Hobbs et al., 2008 submitted to MNRAS

How many pulsars do we need to observe? How often? What timing precision? How do we make a detection?

Jenet et al. 2005





Must look for correlated residuals

Need ~20 pulsars, observed of ~5 years with rms timing residuals ~100ns

Gravitational wave detection

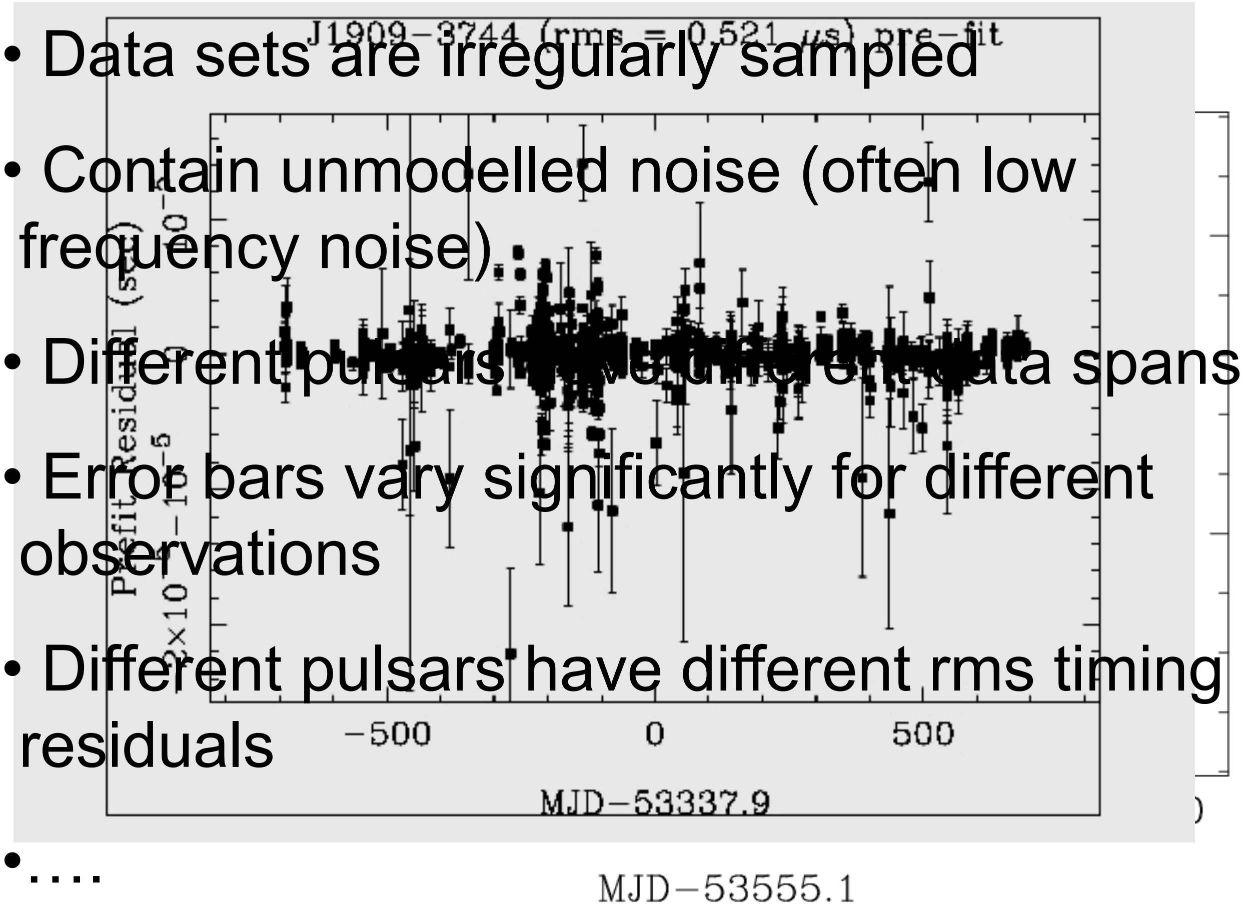
Basic ideas

Jenet et al. 2005

Initial data sets

Review papers of

Manchester and/or Hobbs



- Data sets are irregularly sampled
- Contain unmodelled noise (often low frequency noise)
- Different pulsars have different data spans
- Error bars vary significantly for different observations
- Different pulsars have different rms timing residuals
- ….

Gravitational wave detection

Basic ideas

Jenet et al. 2005

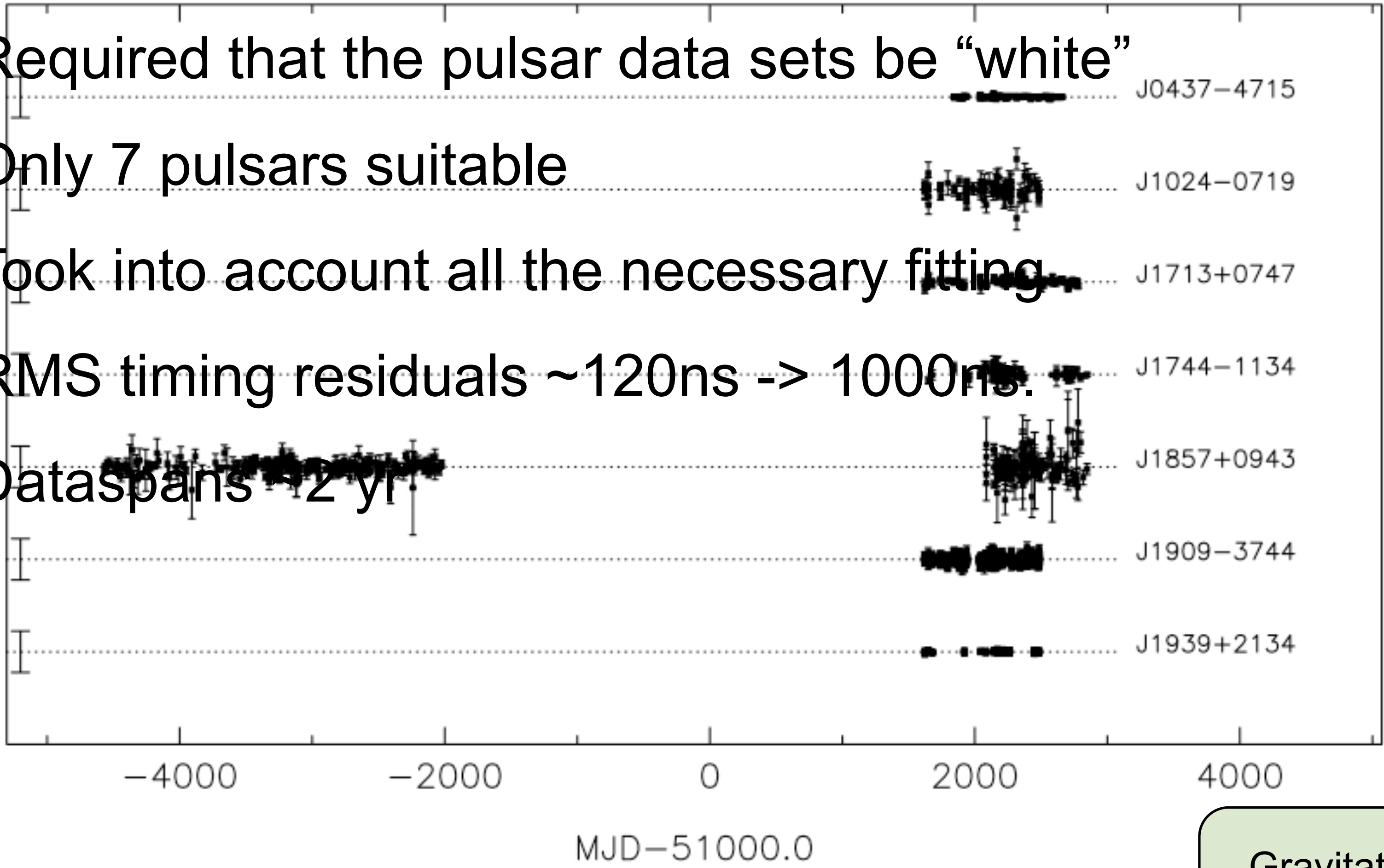
Initial data sets

Manchester, Hobbs

Get first limit on GW background

Jenet et al. 2006

- Required that the pulsar data sets be “white”
- Only 7 pulsars suitable
- Took into account all the necessary fitting
- RMS timing residuals ~120ns -> 1000ns.
- Dataspans ~2 yr



Gravitational wave detection

Basic ideas

Jenet et al. 2005

Initial data sets

Manchester, Hobbs

Get first limit on GW background

Jenet et al. 2006

Improve timing residuals

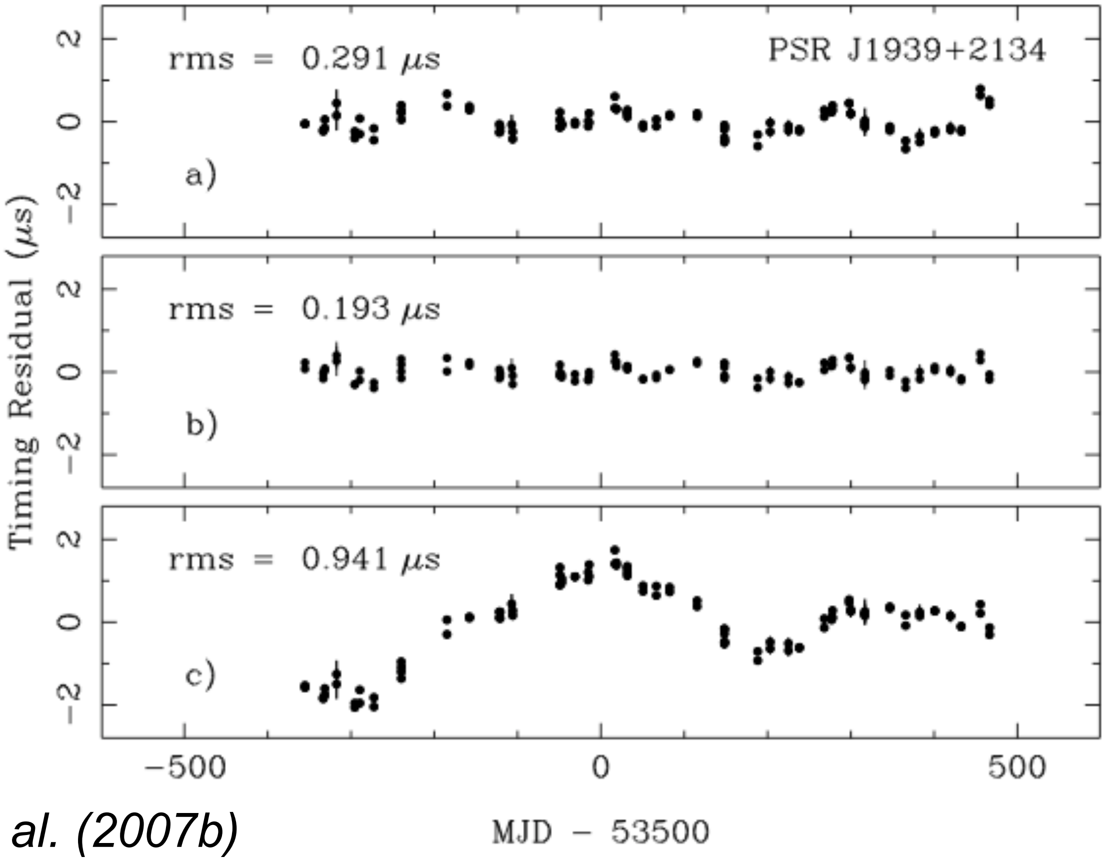
New limit technique (Joris' talk)

Gravitational wave detection

Improving our timing residuals 1/3

ISM issues - fixing variations in the delay caused by the plasma between the pulsar and the Earth

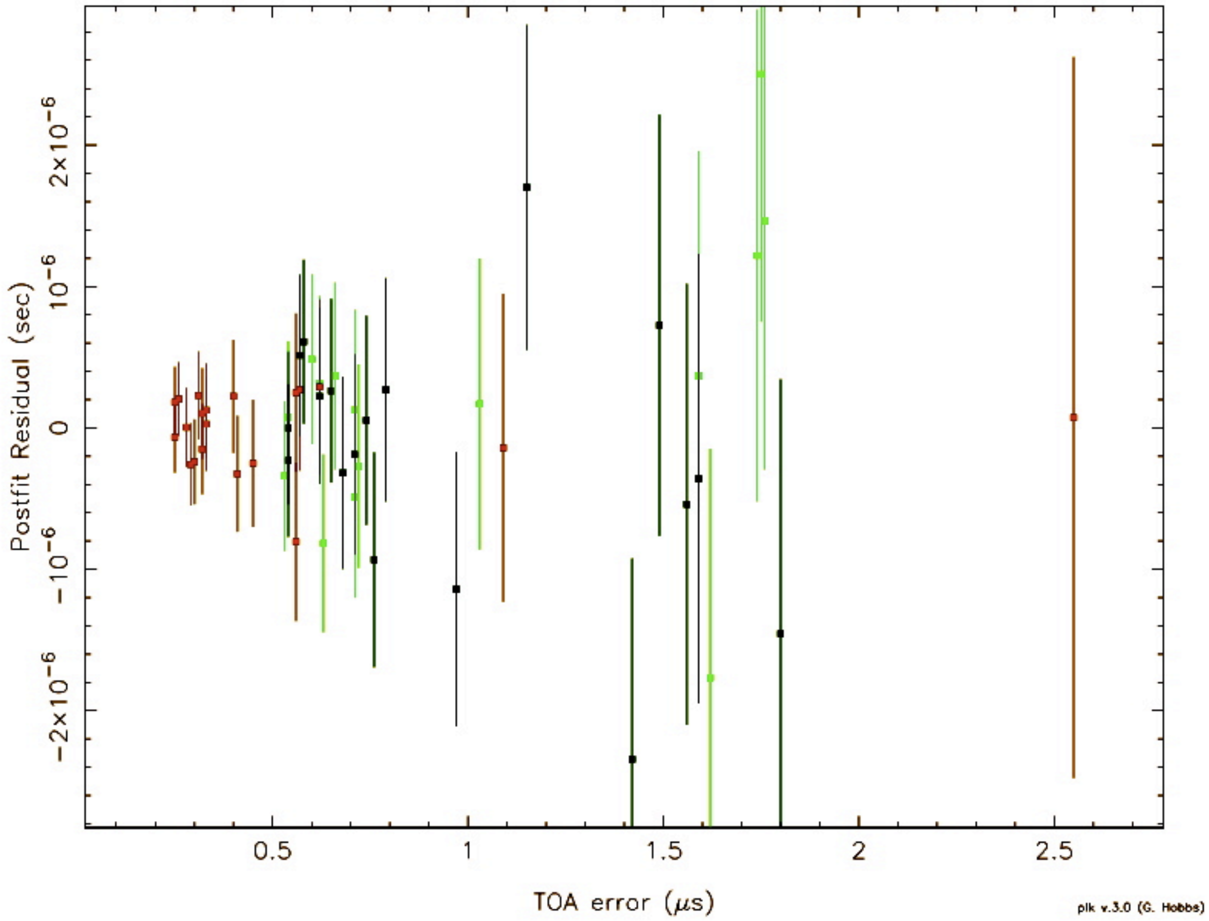
Compare results at multiple observing frequencies



- *You et al. (2007a), You et al. (2007b)*
- *"The Solar wind is signficant when the line of sight to the pulsar passes within ~60^o of the Sun"*

Improving our timing residuals 2/3

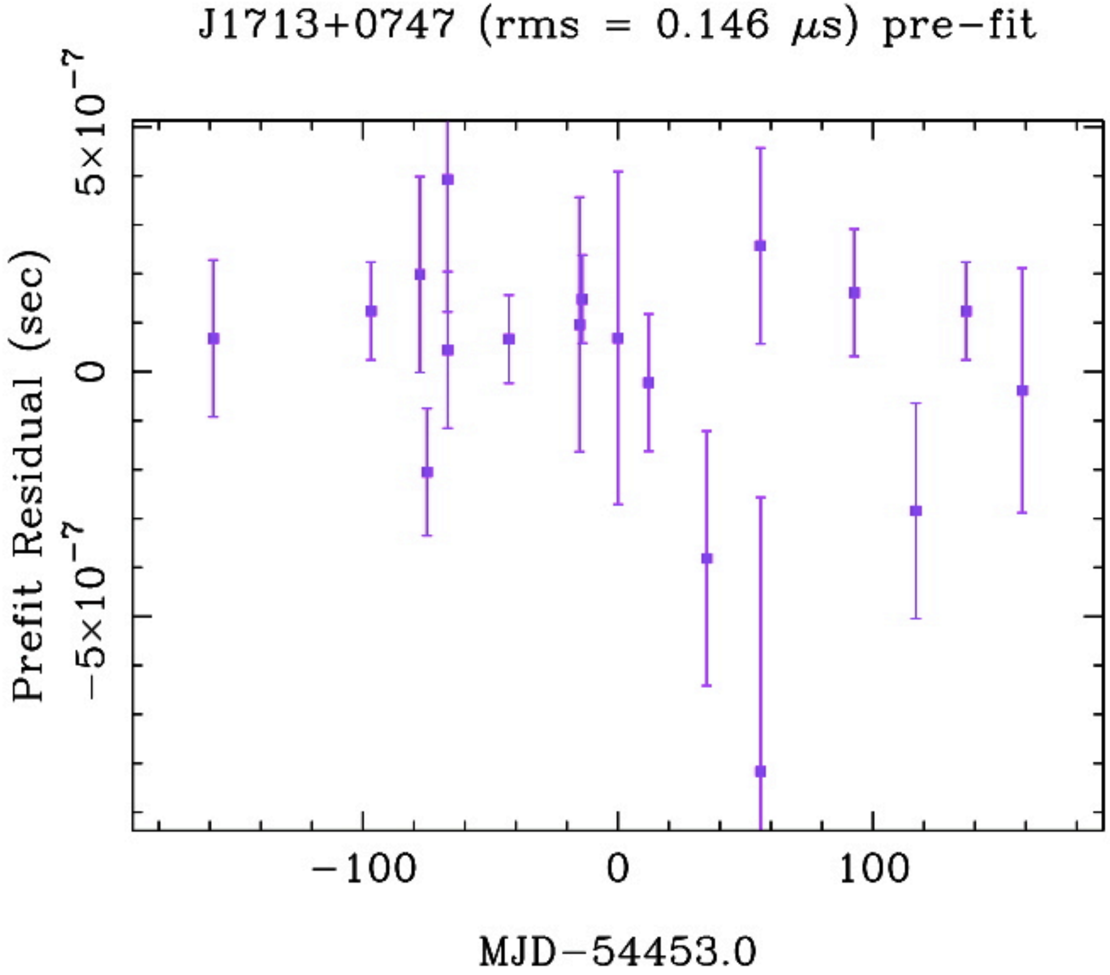
build better instrumentation



New digital filterbanks, coherent dedispersion systems, RFI mitigation systems …

Improving our timing residuals 3/3

improved calibration and data processing



Basic ideas

Jenet et al. 2005

Initial data sets

Manchester, Hobbs

Get first limit on GW background

Jenet et al. 2006

Improve timing residuals

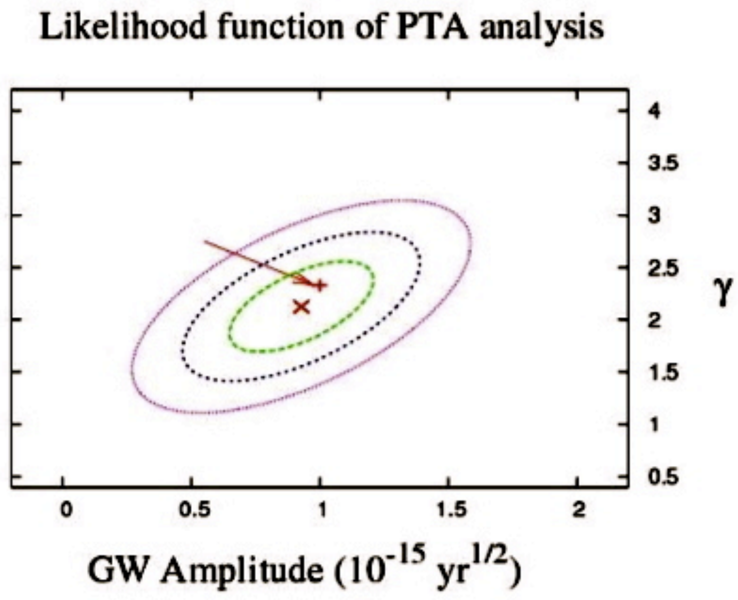
New limit technique (Bill's talk)

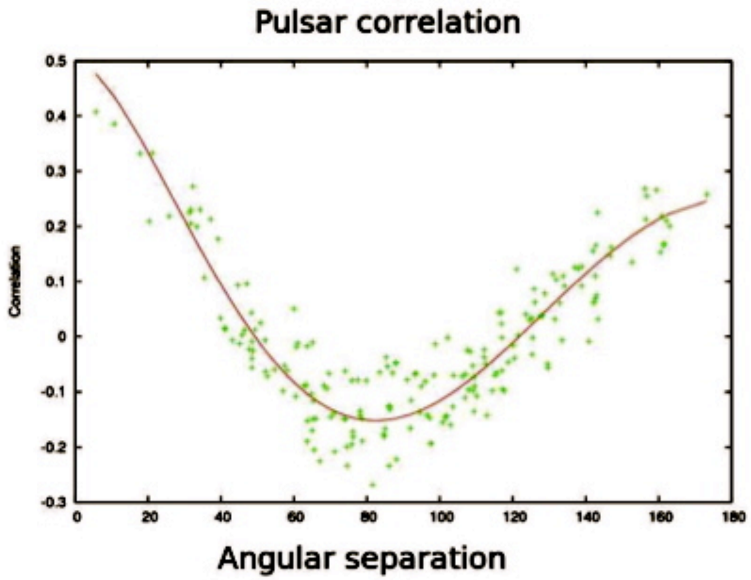
Bayesian Detection technique

Gravitational wave detection

A Bayesian technique for detecting gravitational waves

- Work carried out by Y. Levin and R. van Haasteren.





A Bayesian technique for detecting gravitational waves

- Problems:
  - slow (needs lots of computing time)
  - requires model of intrinsic pulsar noise (which is unknown)
  - currently doesn't deal with variations in error bars for different observations
- Recent developments (frequentist technique) - Bill's talk

Basic ideas

Jenet et al. 2005

Initial data sets

Manchester, Hobbs

Get first limit on GW background

Jenet et al. 2006

Improve timing residuals

New limit technique (Bill's talk)

Bayesian Detection technique

?

Gravitational wave detection

After detection!

If/when we make a detection

- Obtain A, α
- Can state whether the background is from black hole binaries, cosmic strings or the early universe (… or something else)
- If from black hole binaries then constrain MBH mass function at low redshift and halo merger rate
- Sesana 2008: we'll have a weak bound on the expected number of MBHBs observable with *LISA*.

Conclusions

- Pulsar timing arrays can *detect* a GW background.
- We need help from the galaxy community to constrain the expected GW background amplitude
- Interesting limits/detection should occur within next ~5 years.