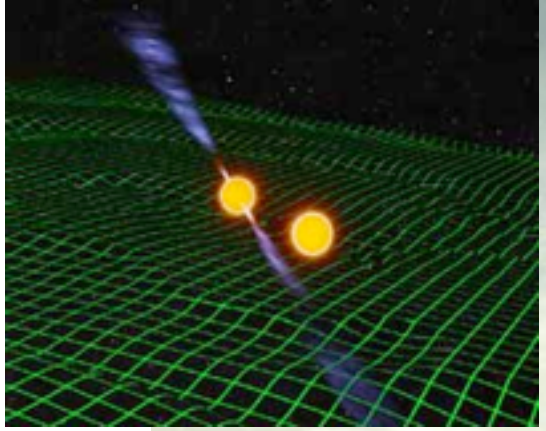

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Developing a pulsar timescale

PPTA

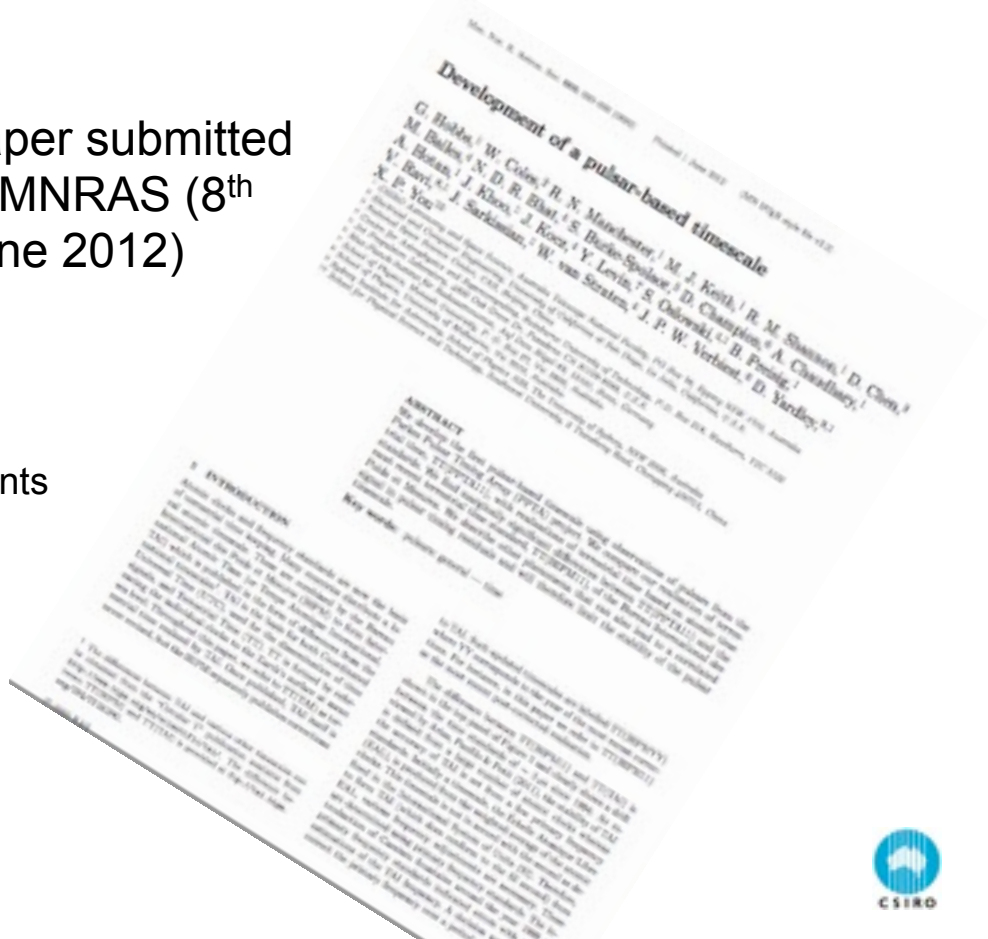
George Hobbs
CSIRO Astronomy and Space Science

CSIRO

Thanks to …

- Bill Coles (UCSD) for algorithmic development
- Dick Manchester, Mike Keith, Ryan Shannon
- Ding Chen (giving the initial impetus for the project)
- All of PPTA team

Paper submitted to MNRAS (8th June 2012)



http://www.ipta4gw.org/wiki/doku.php?id=preprints

Summary

- 1) Have algorithm that can identify any time standard errors within a pulsar data set
- 2) Have applied the algorithm to the extended data release 1 from the Parkes Pulsar Timing Array.
- 3) Can use the pulsar observations to find errors in TT(TAI)
- 4) No highly significant errors found in TT(BIPM11)
- …
- 5) Should get a huge boost in sensitivity with EPTA and NANOgrav data => IPTA project accepted by IPTASC (26/06/2012)

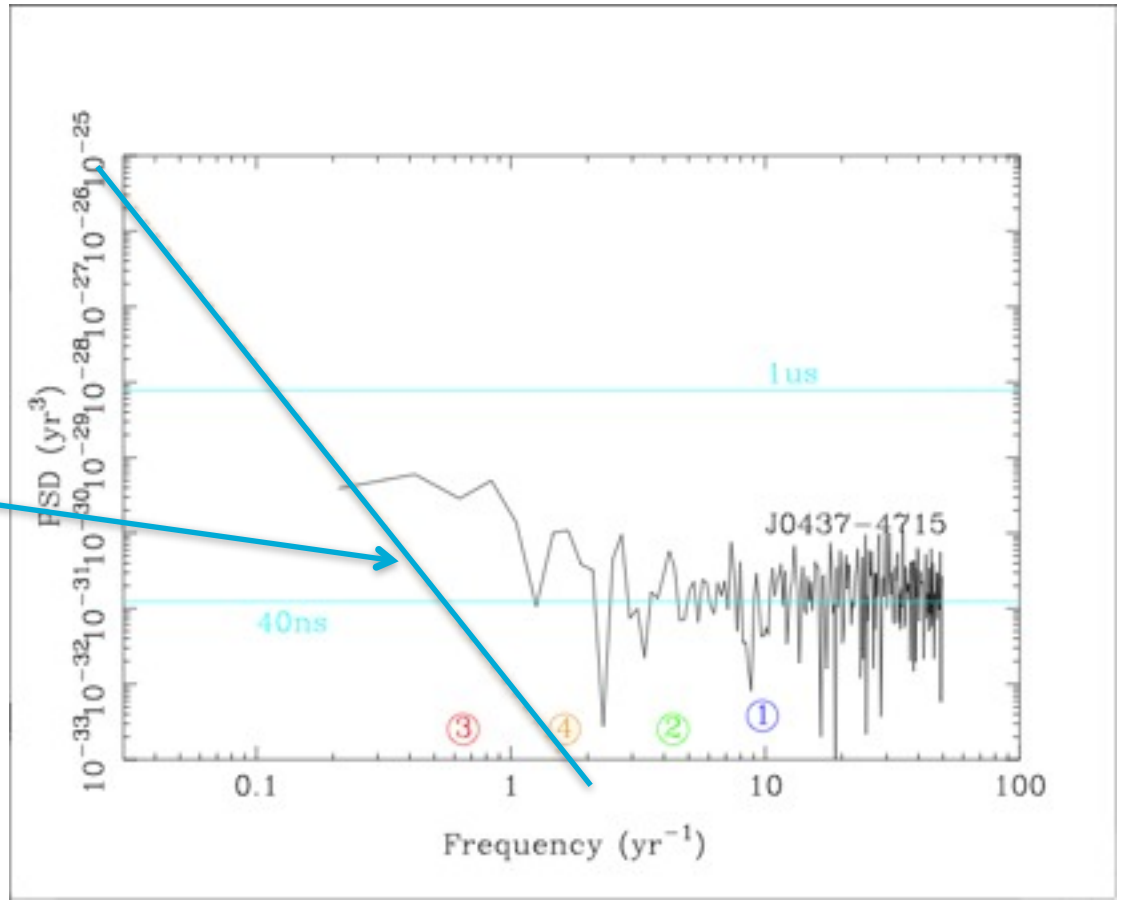
Purpose of talk

- 1) Why should the IPTA care about time standards
- 2) Describe the algorithm used
- 3) Highlight the current PPTA results
- 4) Show the improvement expected using IPTA data sets

Why does the IPTA care?

- Simulate GWB using tempo2
- Actual PPTA PSR J0437-4715 observations

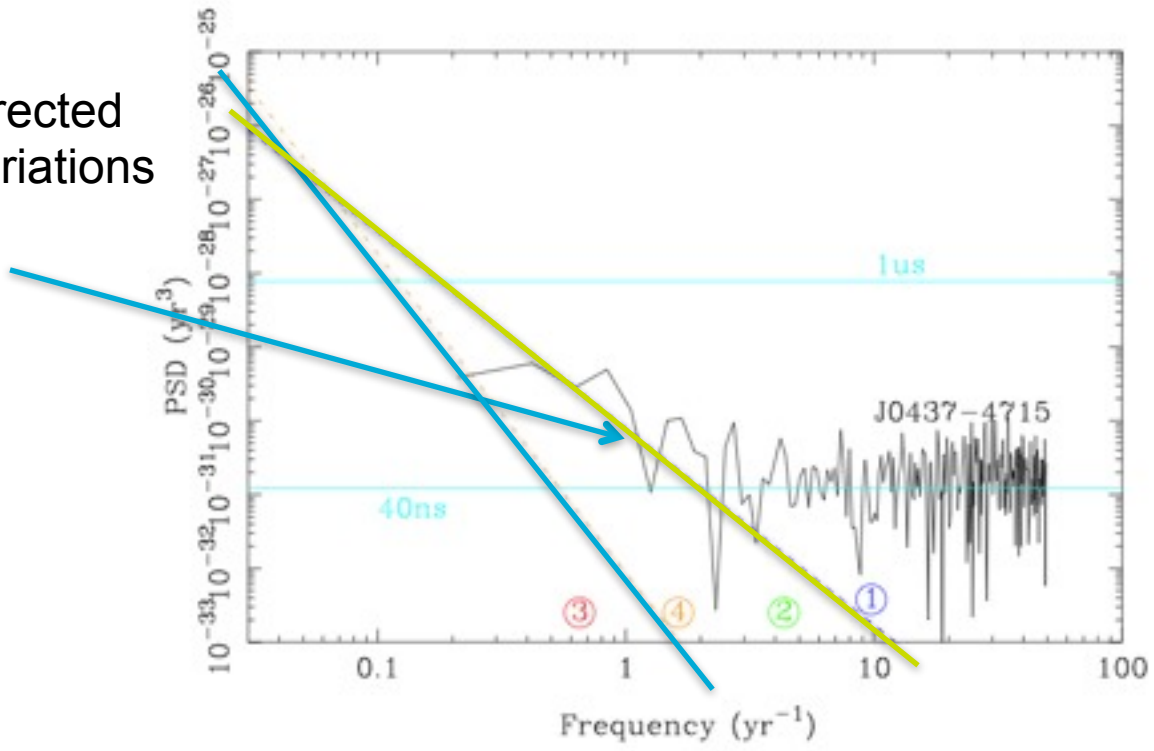
10^{-15} GW background



Why does the IPTA care?

- Use prediction of expected signal caused by dispersion measure variations

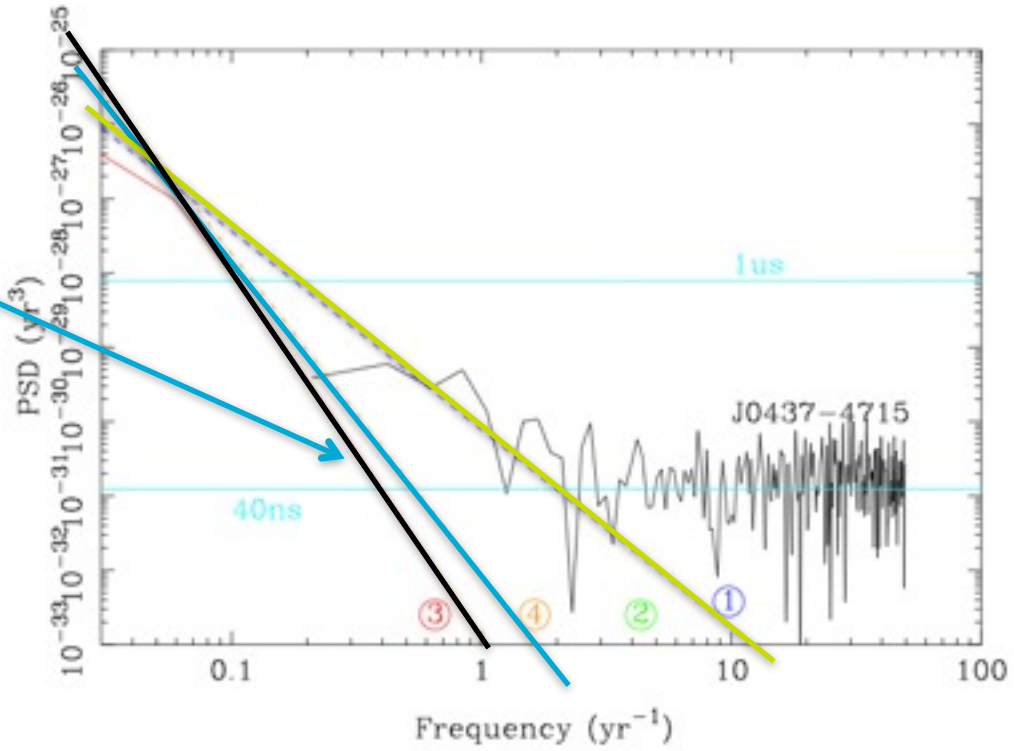
Uncorrected
DM variations



Why does the IPTA care?

- Compare JPL ephemerides DE421 with DE414

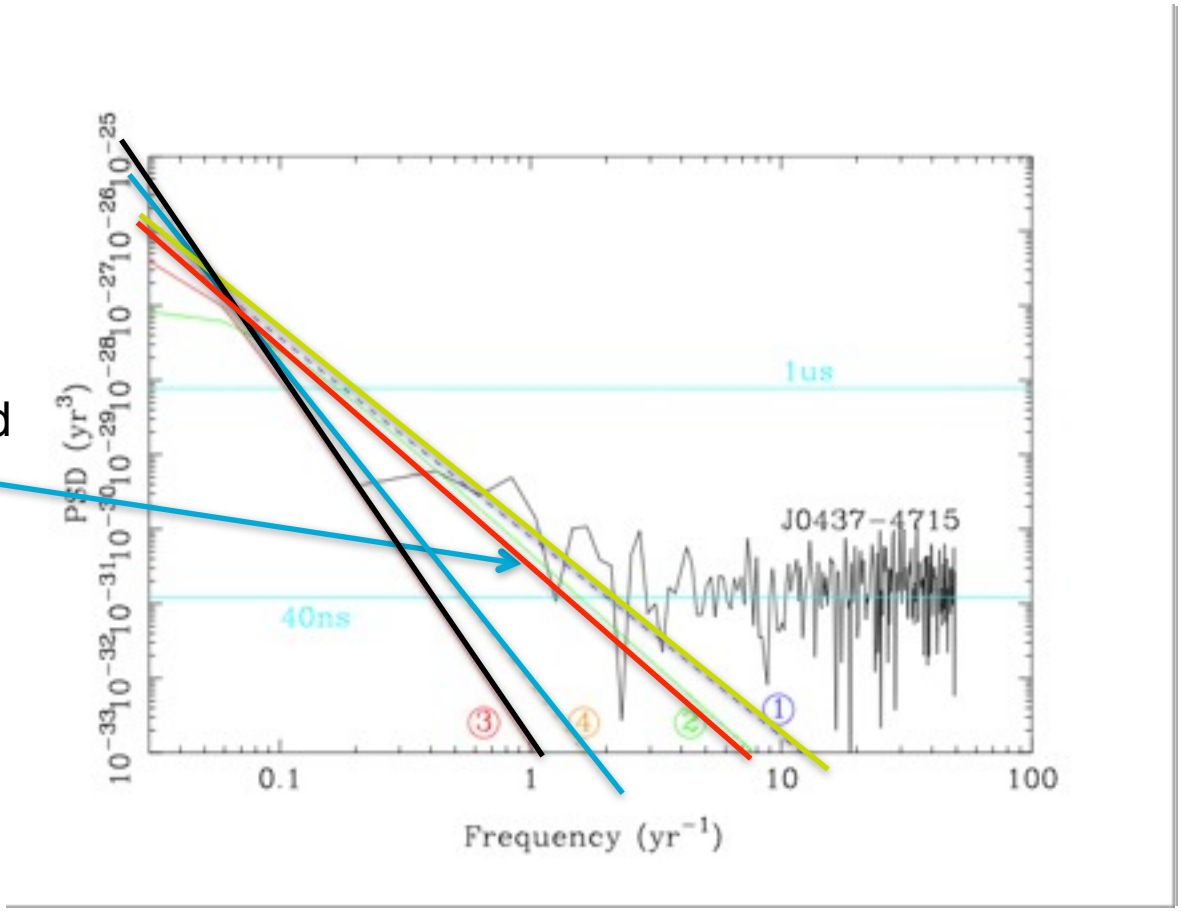
Possible errors in solar system ephemeris



Why does the IPTA care?

Compare two realisations of terrestrial time TT(TAI) and TT(BIPM11)

Possible errors in timestandard

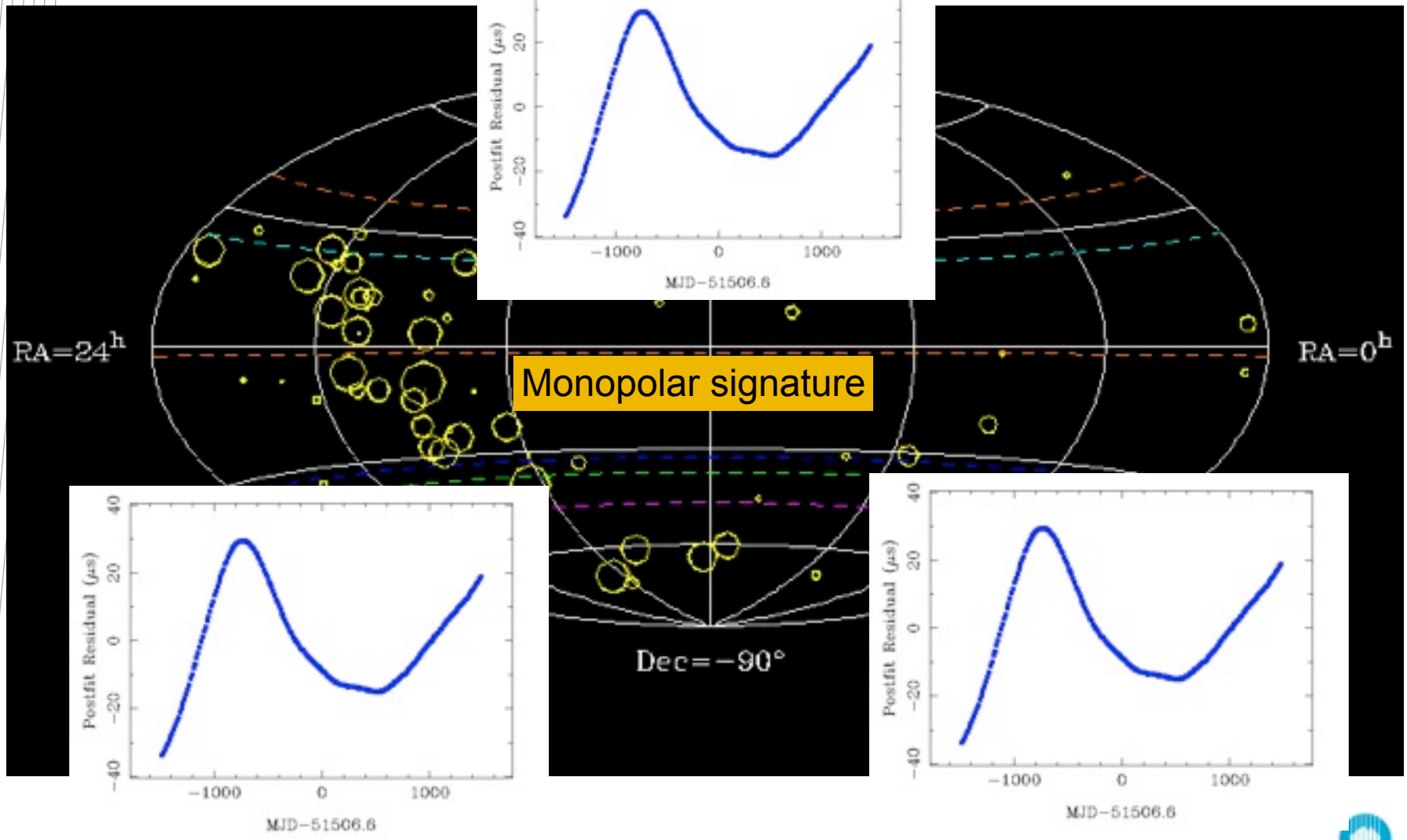


Terrestrial time, TT

- Theoretical, ideal time standard (actual clocks can only approximate this time standard)
- Most commonly used realisation is International Atomic Time (TAI) giving TT(TAI).
- TAI is never revised once published => possible that errors become known, but will remain uncorrected
- TT(BIPM12) is the current best realisation of terrestrial time

- In this talk will consider using pulsars to obtain a realisation of terrestrial time TT(PPTA11) and compare to TT(TAI) and TT(BIPM12).

Terrestrial time standard irregularities will induce the same residuals in each pulsar

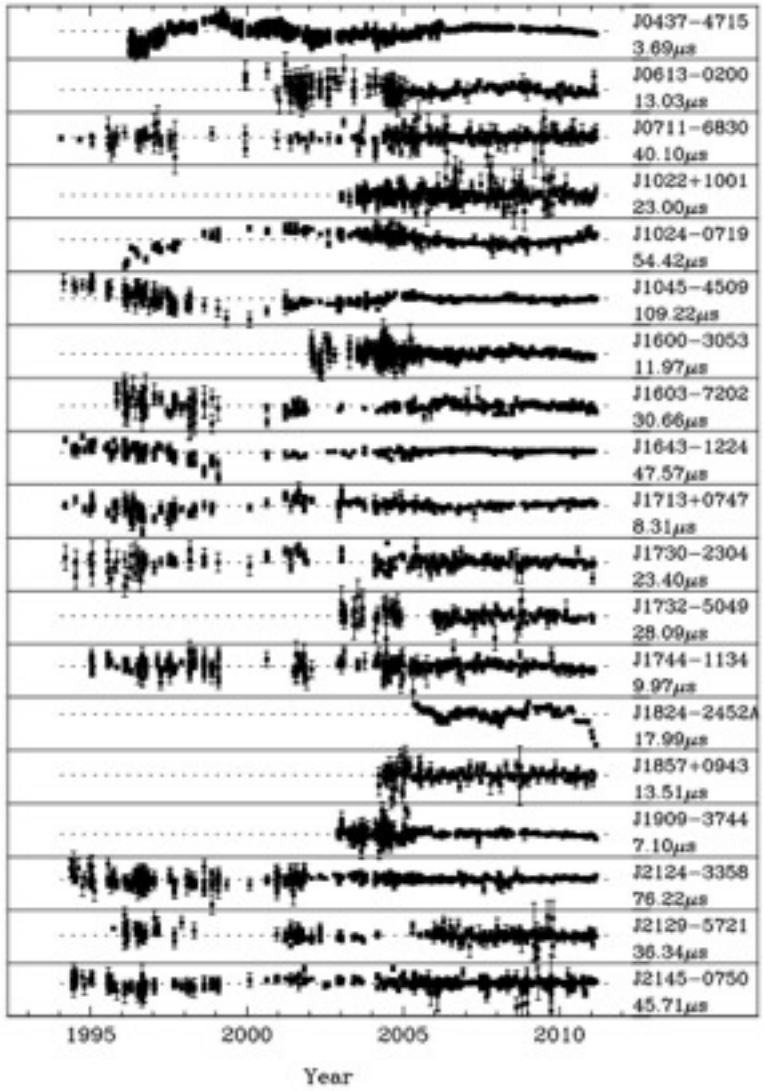


It’s easy

- All we need to do is to find the signal in the timing residuals that is the same for every pulsar.
- That correlated signal corresponds to TT(PPTA11)-TT(TAI) and therefore errors in TT(TAI) can be identified

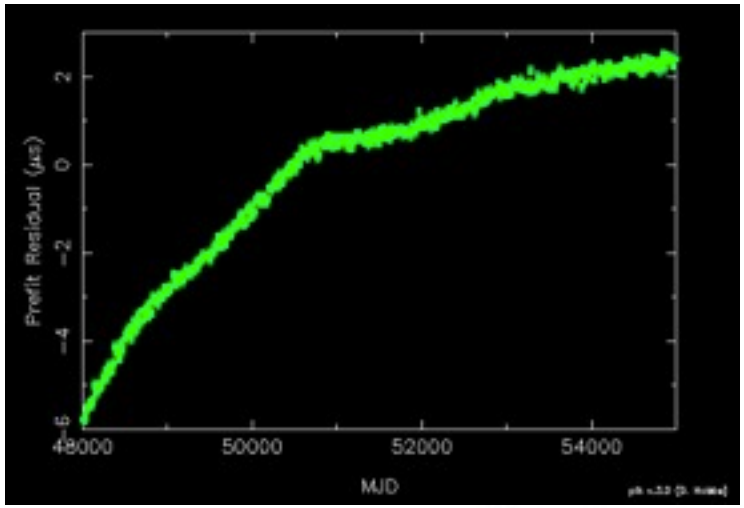
Why is it hard?

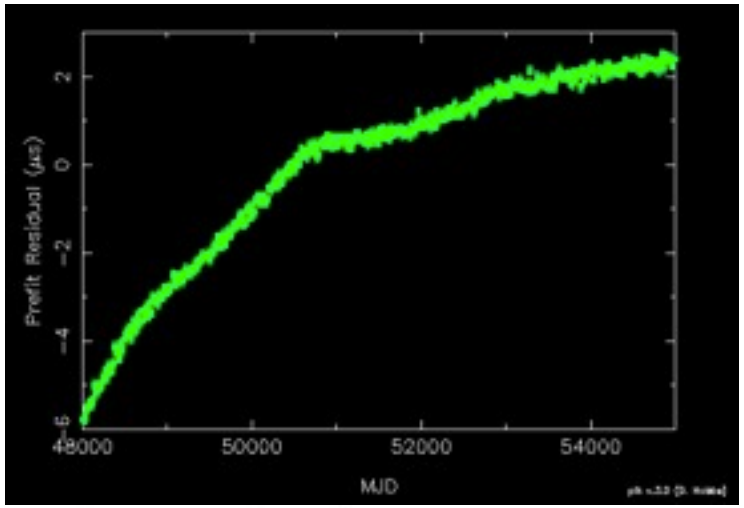
- Because we have to use real data sets!

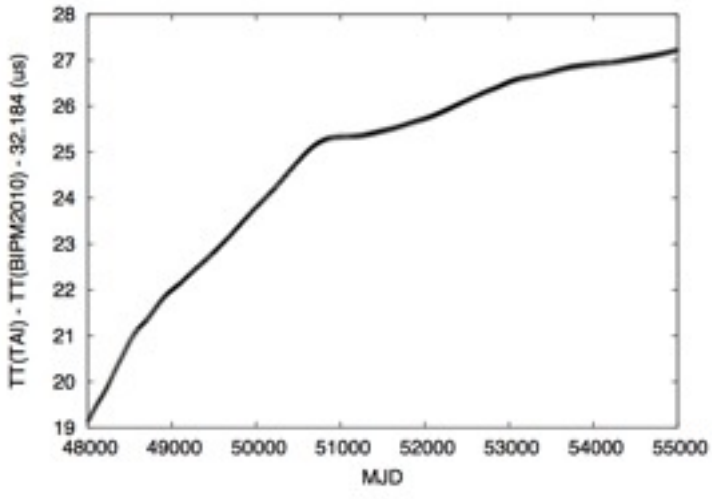


Why it is hard

- Consider two pulsar data sets.

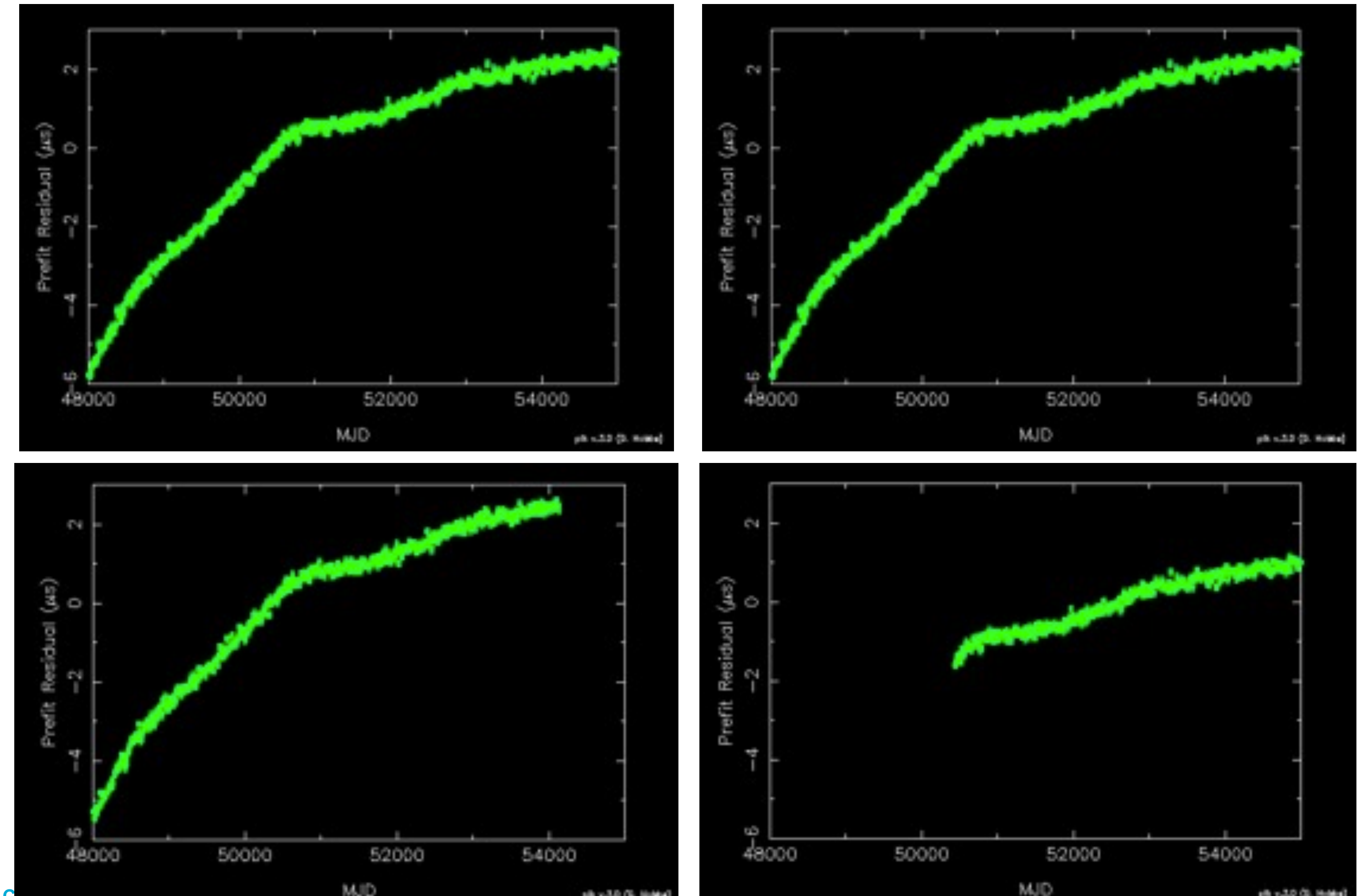






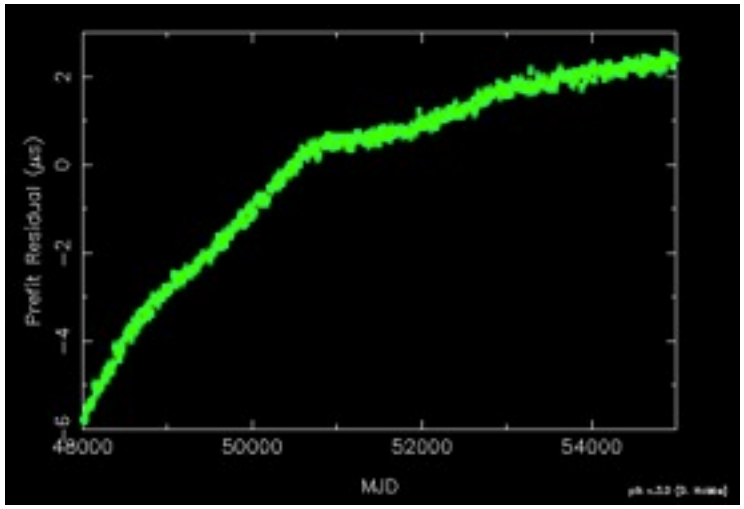
An example

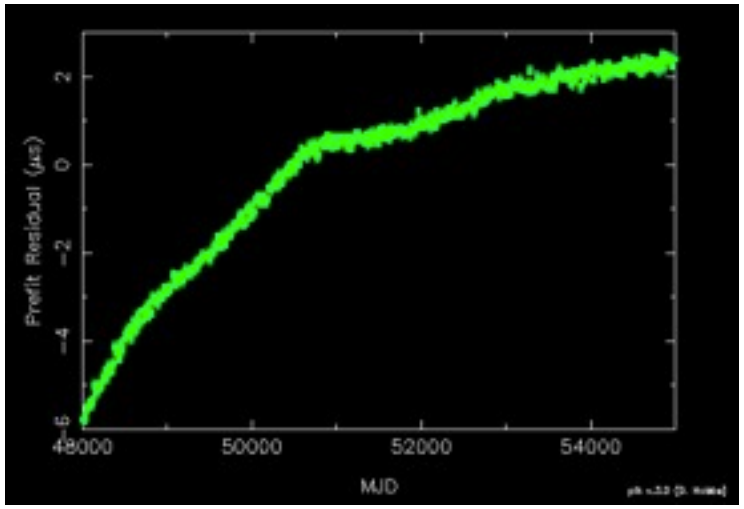
- Have different data spans

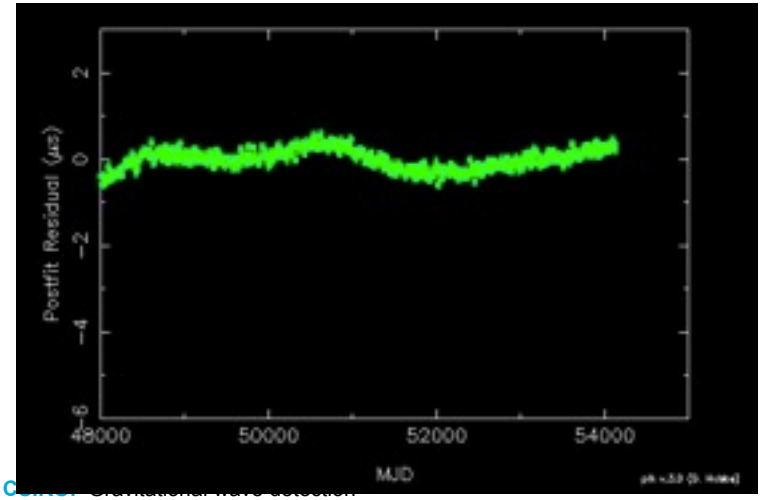


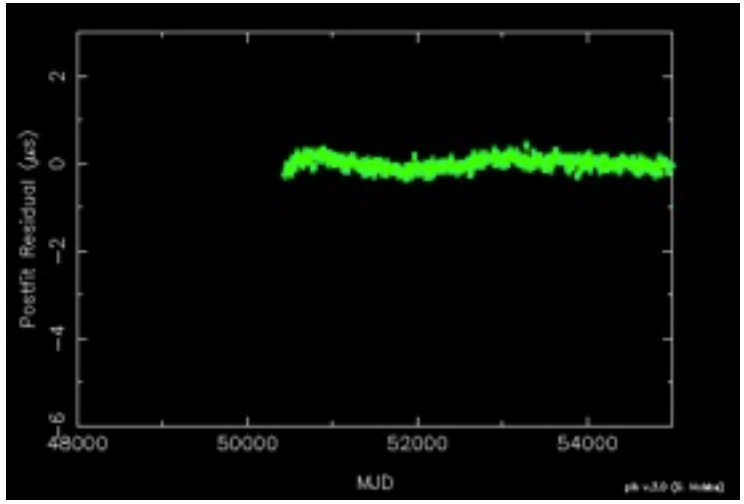
An example

- Fit for the pulse frequency (F0) and its derivative (F1)



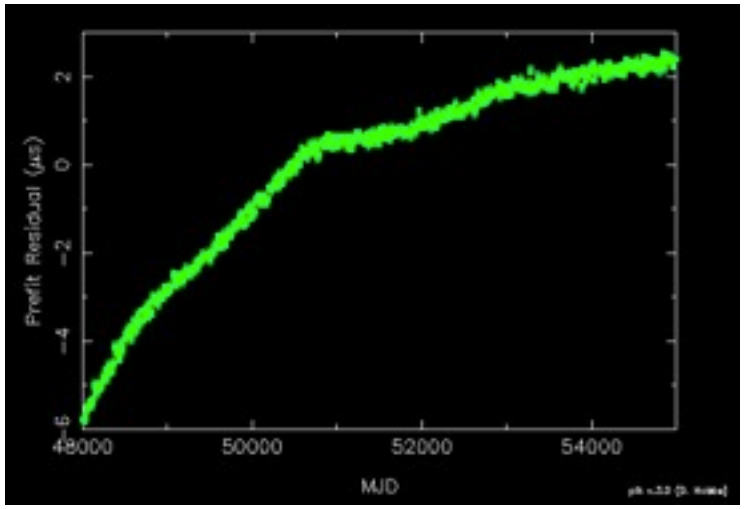


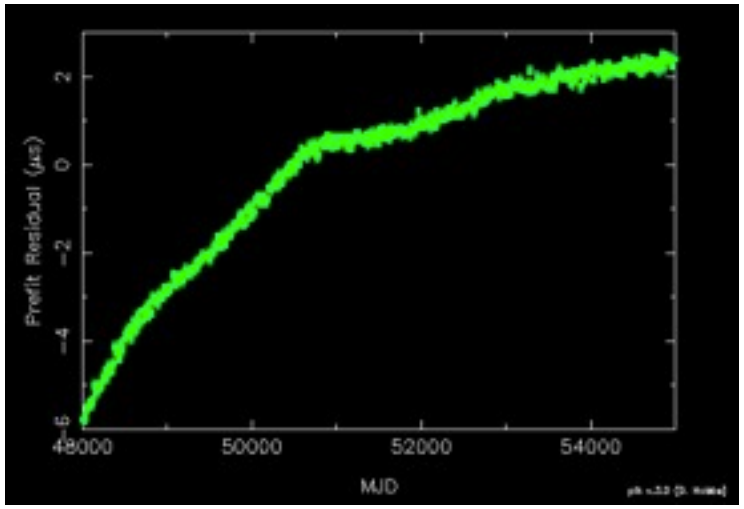


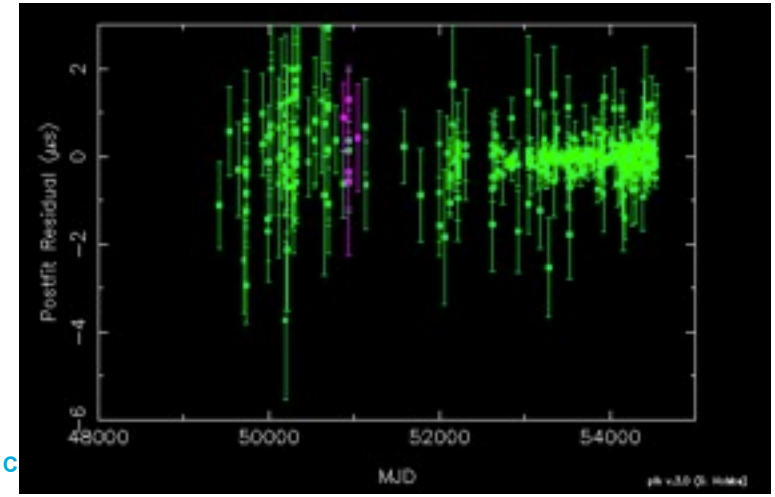


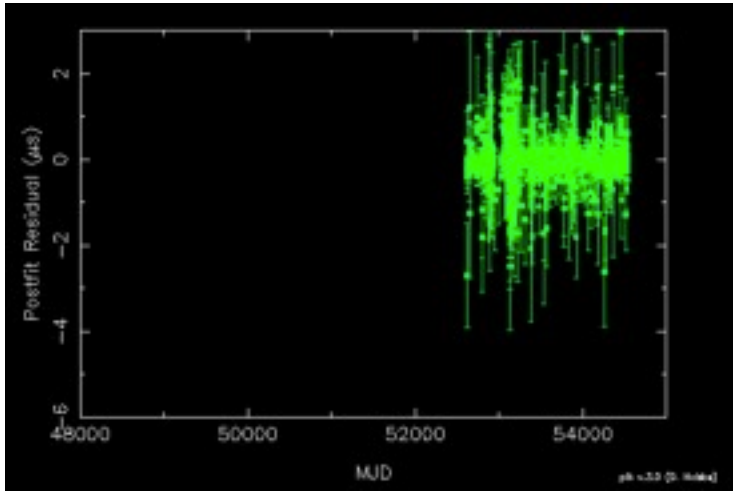
An example

- Add in realistic amounts of white noise



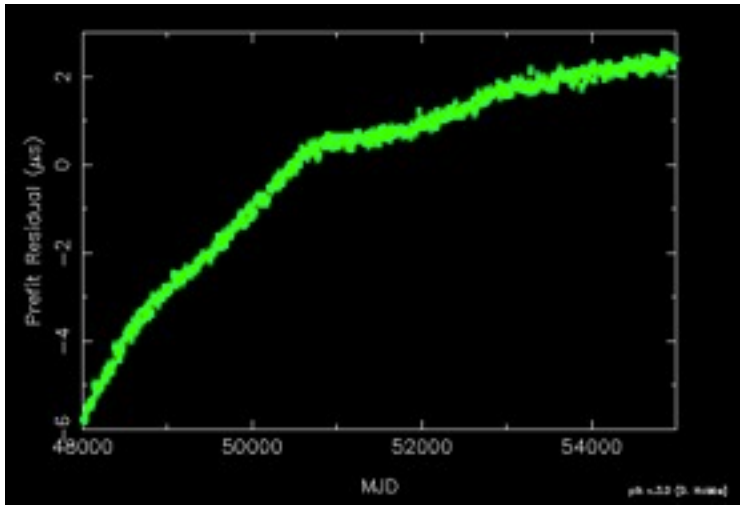


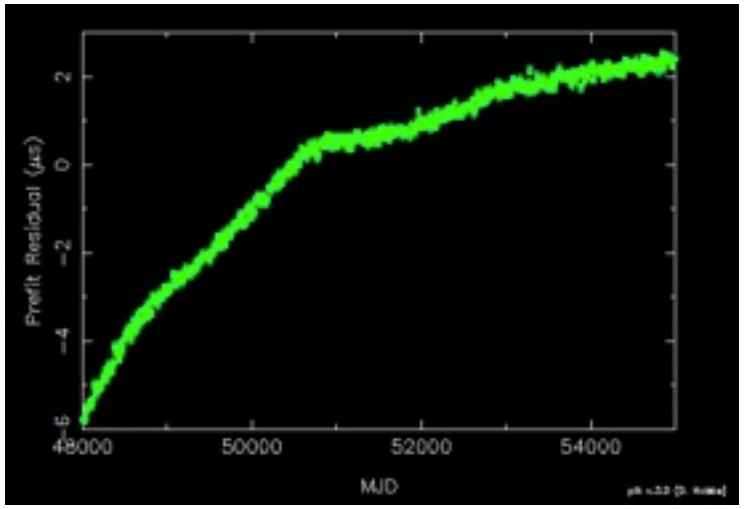


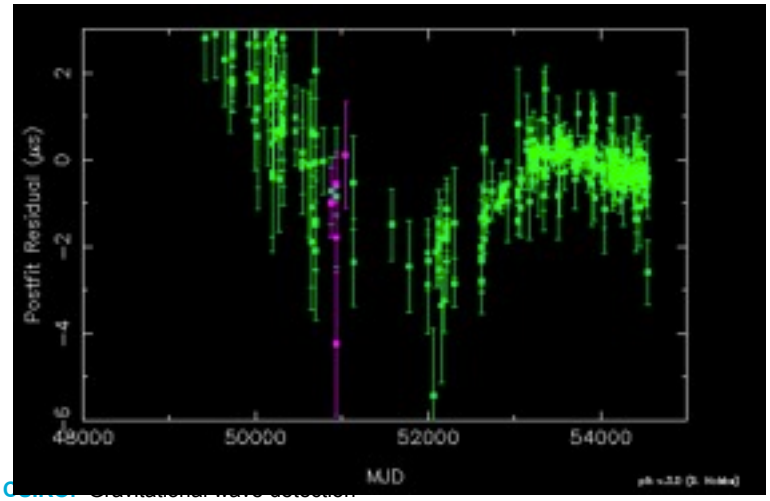


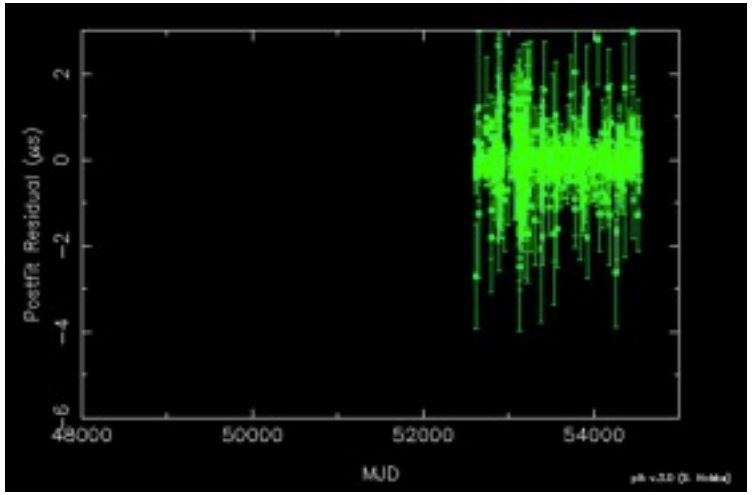
An example

- Add in some unexplained timing irregularities









Important notes

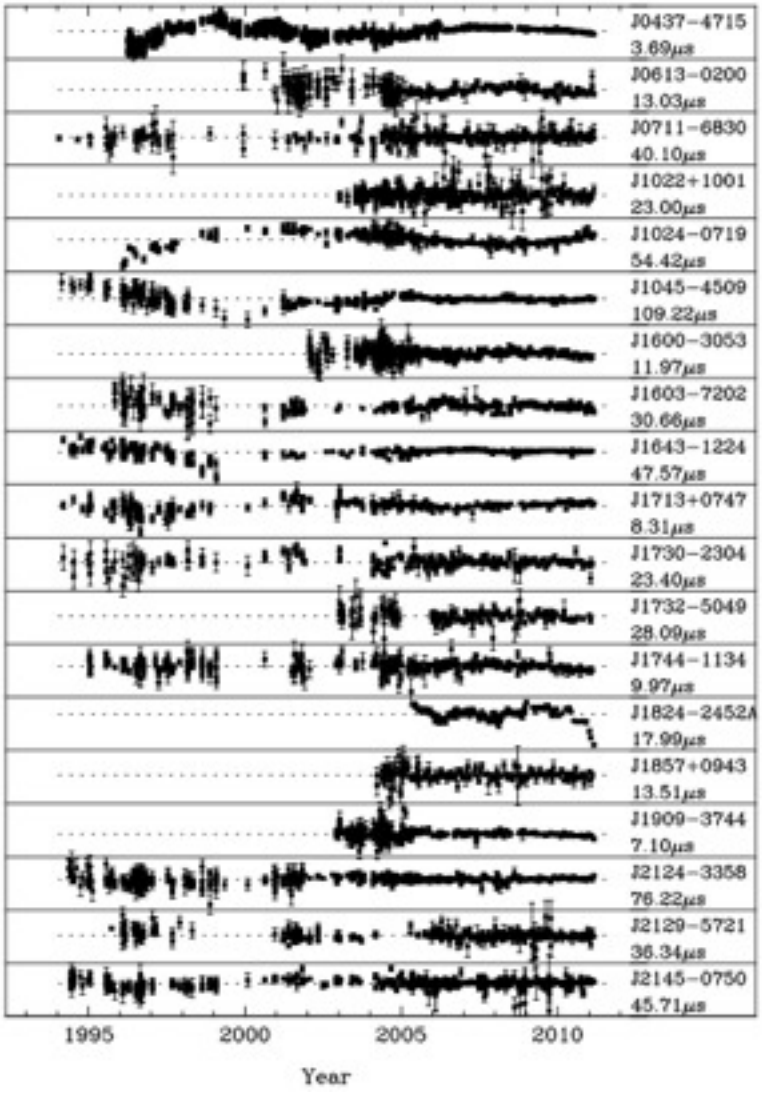
- We can never recover the linear and quadratic irregularities in a time standard
- For data sets with different data spans, it is not possible to use a simple “weighted-average” method to determine the ensemble pulsar time standard.

Technique

- Include a function, $\Delta_c(t)$, in the timing model that describes the clock errors.
- Very similar to Mike/Bill's "common mode" signal, but is now "common" to all pulsars
- We define $\Delta_c(t)$ using a set of equally spaced samples with linear interpolation
- Use tempo2 constrained fitting procedure to ensure that $\Delta_c(t)$ is not covariant with the pulsar's pulse or astrometric terms
- Use tempo2 Cholesky (generalised least-squares-fitting) procedure to account for timing noise
- Use tempo2 global fitting procedures to fit for each pulsar's pulse, astrometric and orbital parameters individually whilst globally fitting for $\Delta_c(t)$.

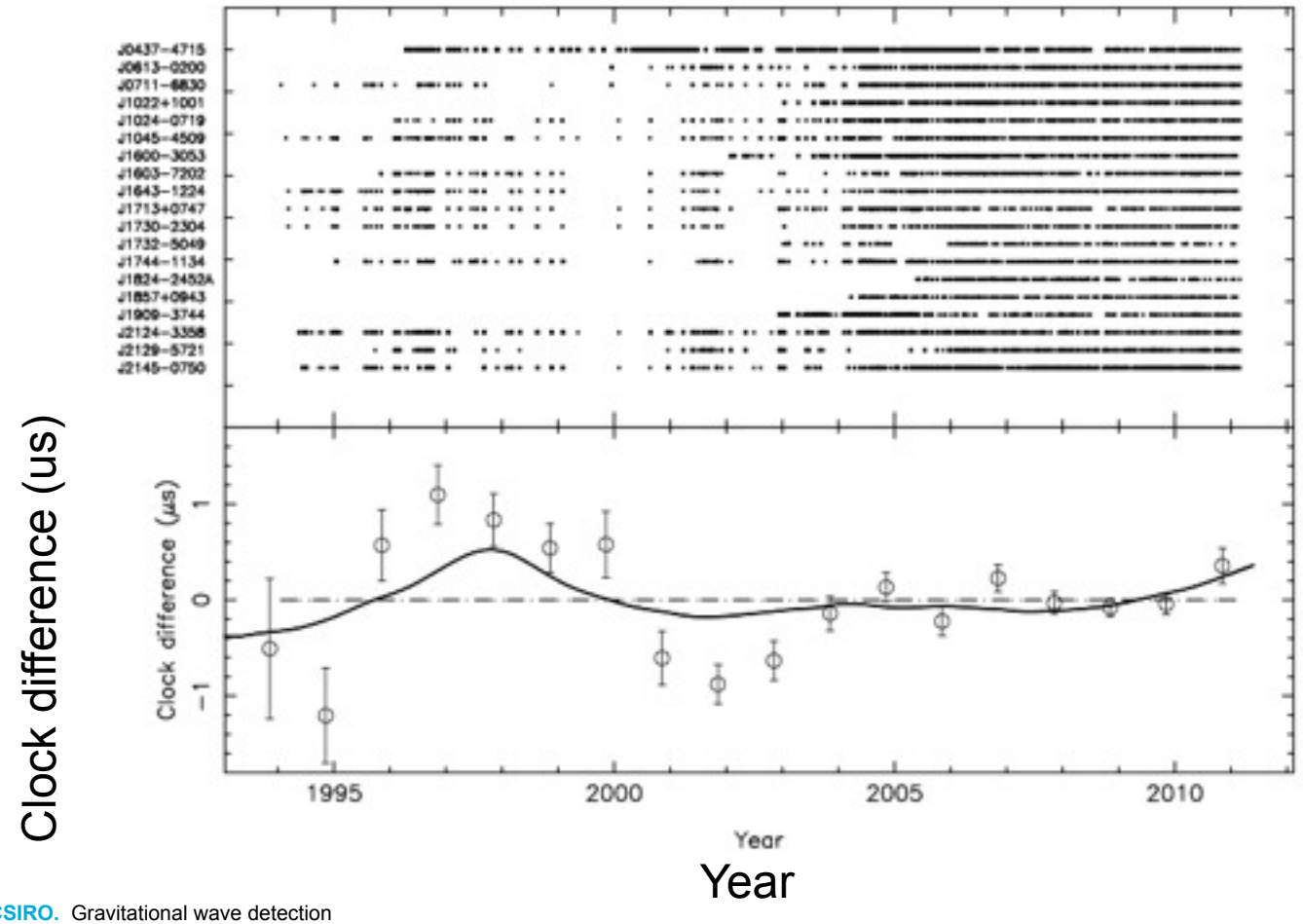
The dr1e data sets

- See Dick's talk
- Each pulsar has a different data span
- Data sampling is irregular with the most recent data being more uniform than earlier data
- Very few observations exist around 2000
- ToA uncertainties are variable
- Timing noise is evident
- RMS timing residuals vary widely



The result

- The paper discusses lots of tests of the algorithm. Here we just show the result.



Sampling for different pulsars

Results/discussion in the paper

- Lots of discussion on the error bars (being correlated) and the implications of the slight discrepancies with the expected value
- ---- No obvious error in TT(BIPM11) , but can recover errors in TT(TAI)

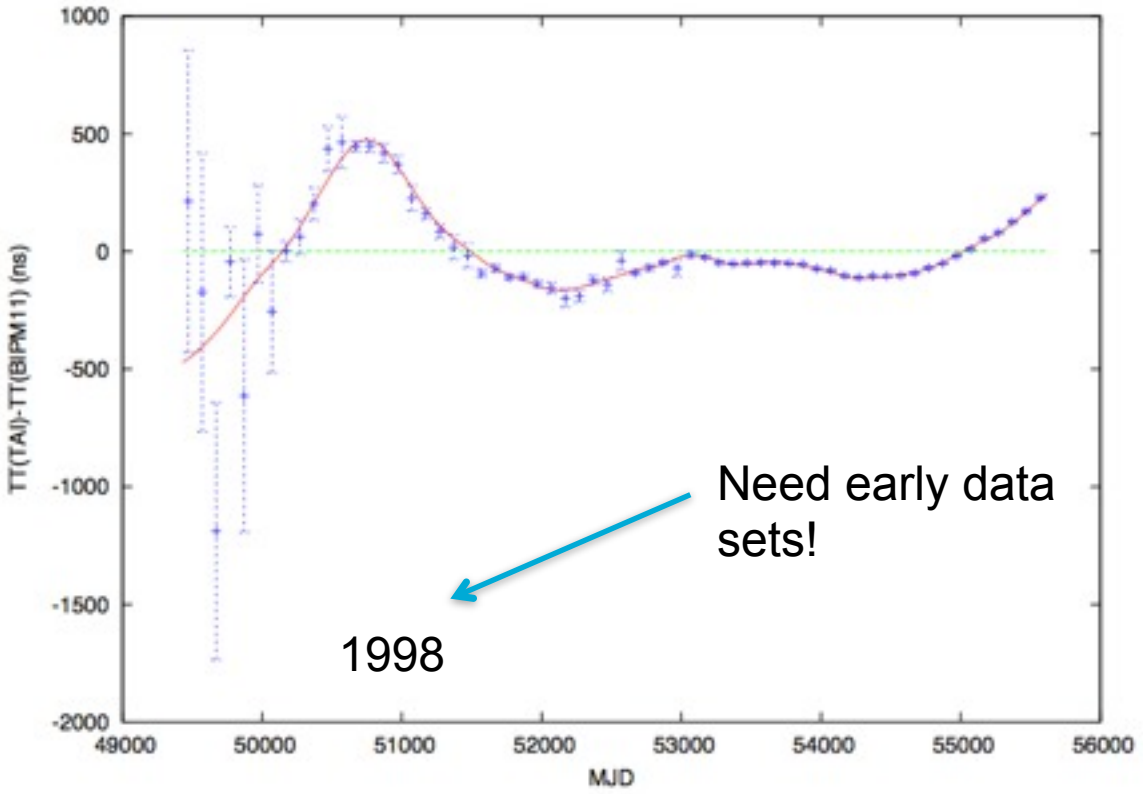
- High precision pulsar timing experiments should not be using TT(TAI)
- A GWB could not be causing a significant correlation in our residuals that mimics a clock error (yet)

Adding in IPTA data

- IPTA will provide data sets spanning ~20 years for a few pulsars and very high quality data sets for ~5 years on >30 pulsars.
- [SIMULATED DATA]

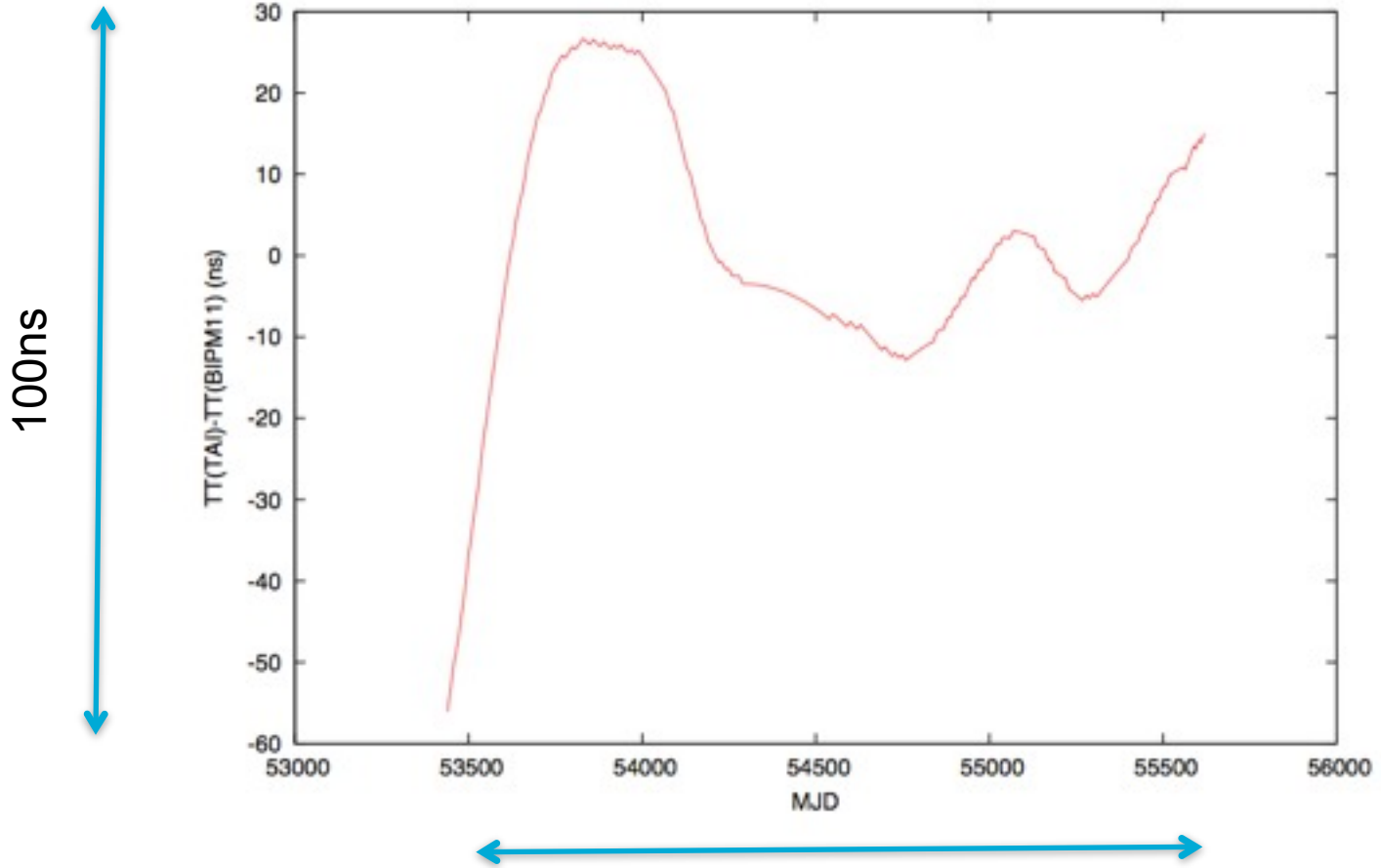
Assume:

-Expected data sets
-White data
-No arbitrary jumps
-…



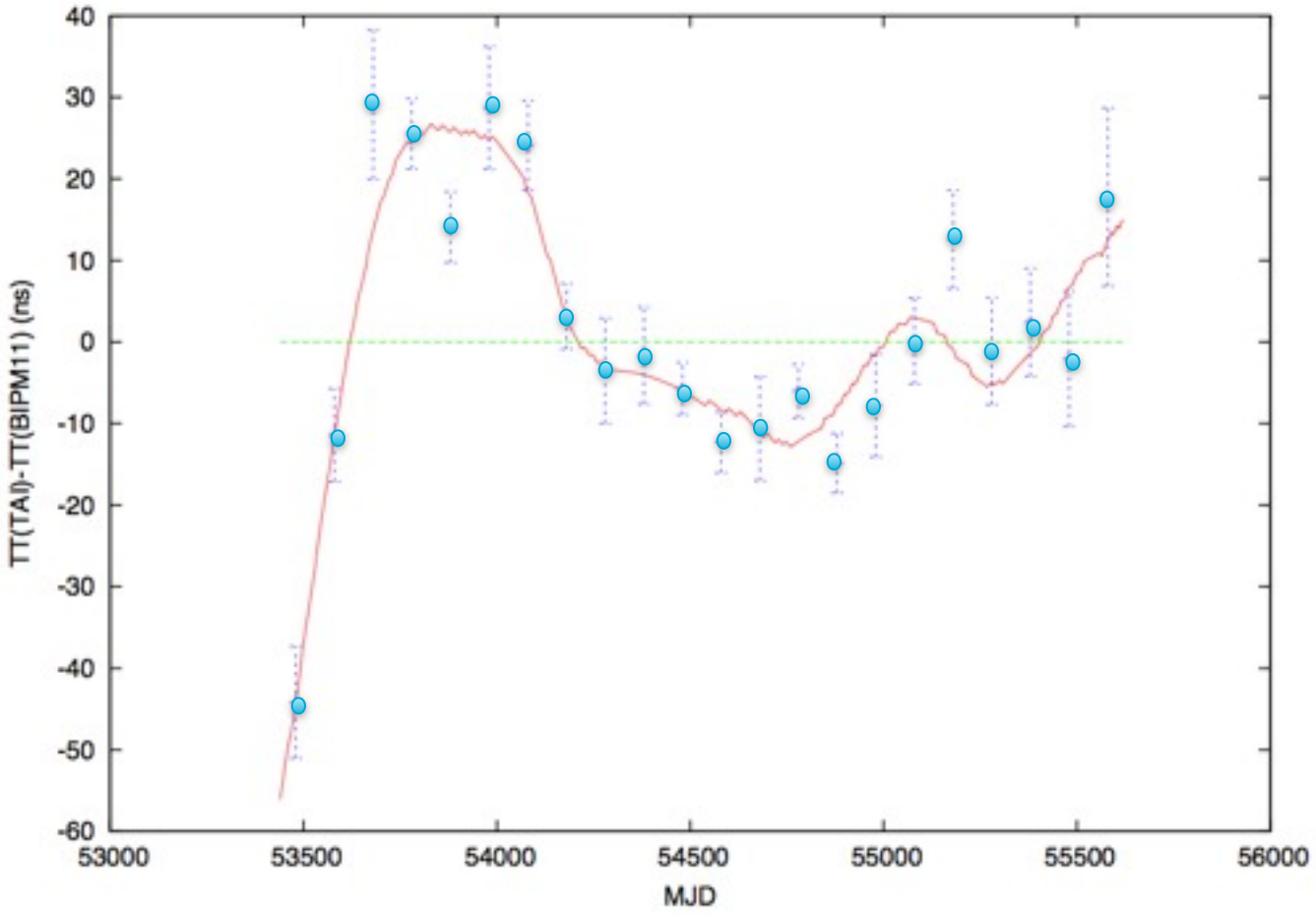
Most recent data

- Clocks have significantly improved since the year 2000 … have the pulsars kept up?



Expected result with combined PPTA + Demorest data

- [Simulated data]



Conclusions

- Pulsar observations can be used to develop a pulsar-based time standard
- Algorithm implemented as a tempo2 plugin (“clock”)
- (Takes ~2 minutes to run on the PPTA dr1e data set)
- Paper using PPTA pulsars published. No major errors found in TT(BIPM11), but can recover errors in TT(TAI)
- Ideal project for the IPTA – reasonably straightforward, exciting results and huge boost in sensitivity with IPTA data sets
- IPTA project accepted – please talk with me if you have ideas/ comments/suggestions … *(can we compare algorithms? How do we combine the data sets? … do we need an ipta4clock.org website? …)*
- Advert: come and visit us sometime in Sydney – check out our “distinguished visitor program” for trips of 4 weeks -> 1 year!
- (http://www.atnf.csiro.au/people/distinguished_visitors.html)