Search for the gravitational wave memory effect *with the Parkes Pulsar Timing Array*

Jingbo Wang, George Hobbs,
Dick Manchester, Na Wang
Xinjiang Astronomical Observatory/CSIRO

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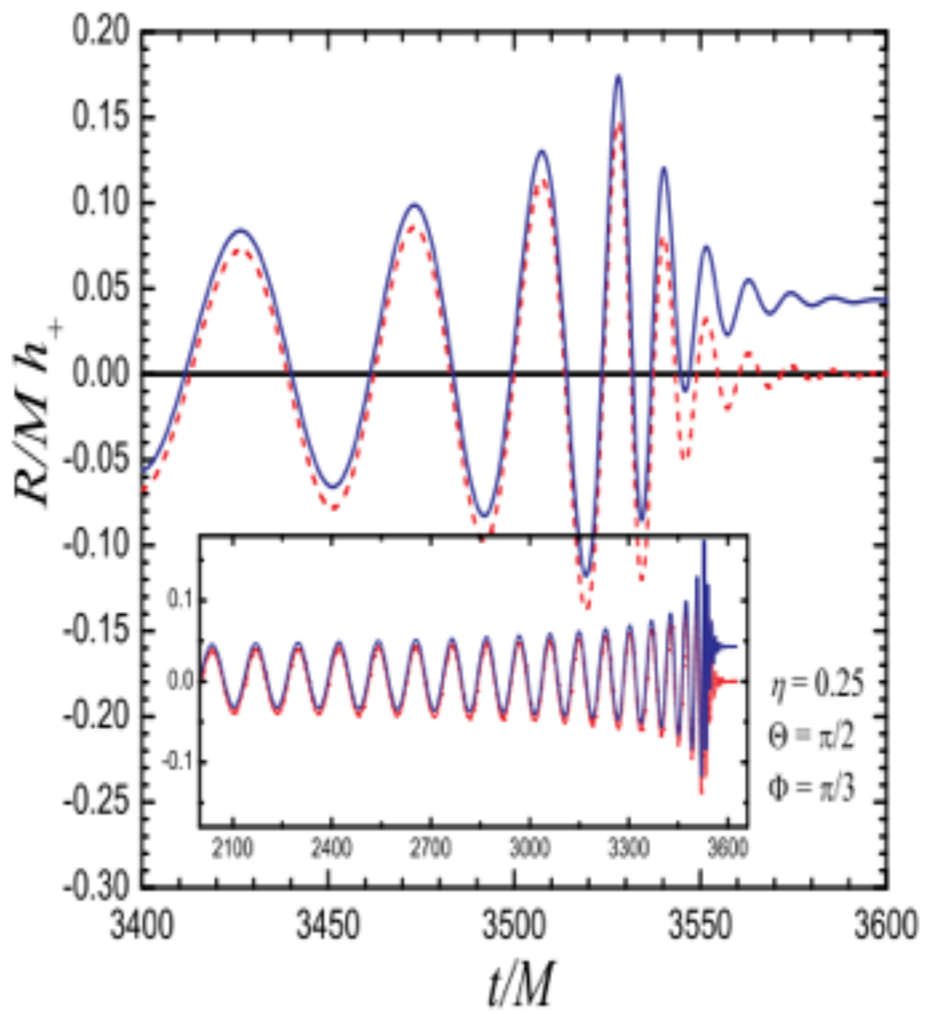
Introduction to Gravitational wave memory effect



- The Gravitational wave memory is a growing, non-oscillatory contribution to the gravitational wave amplitude
- Gravitational waves with memory will leave a permanent imprint on space-time
- Gravitational waves with memory can be produced by merger of binary black holes
- It increases rapidly during the merger phase of binary black holes
- We can treat it as a discontinuous jump propagating through space

$$h^{\rm mem} = 5 \times 10^{-16} \left(\frac{m}{10^8\,{\rm M}_\odot} \right) \left(\frac{1\,{\rm Gpc}}{r} \right)$$

See Fvata 2009, PRD

Introduction to Gravitational wave memory effect

- A gravitational wave will distort space-time between the Earth and the pulsar. This affects the distance traveled by each pulse
- The pulse times-of-arrival will be different from those predicted by timing model, so it will induce timing residuals
- The memory jump would cause a pair of pulse frequency jumps of equal magnitude and the opposite sign (the earth term and the pulsar term)
- The earth term will cause a frequency jump simutanously for all pulsars

The fractional frequency jump
$$\frac{\delta\nu(t)}{\nu} = B(\theta,\phi) \times [h(t) - h(t - r - r\cos\theta)],$$

The angular factor
$$B(\theta,\phi) = \frac{1}{2}\cos(2\phi)(1-\cos\theta).$$

The GWM signal
$$h_+(t) = h^{mem}\Theta(t-t_0), \quad h_\times(t) = 0$$

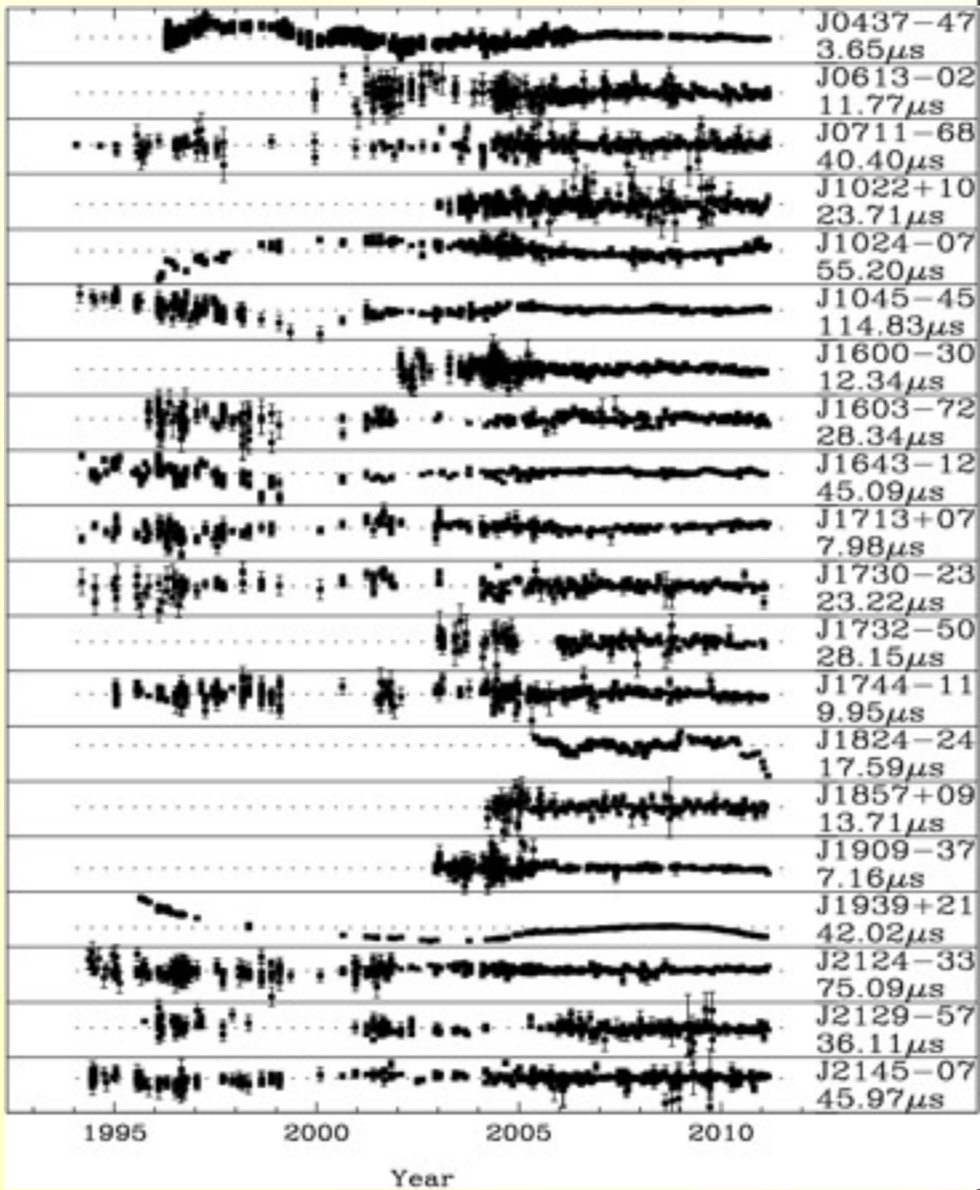
$$\frac{\delta\nu(t)}{\nu} = h^{mem}B(\theta,\phi) \times [\Theta(t-t_0) - \Theta(t-t_1)]$$

The pre-fit residuals
$$s(t)_{\text{prefit}} = \frac{1}{2}h^{\text{mem}}(1-\cos\theta)\cos 2\phi \ (t-t_{\text{B}})\Theta(t-t_{\text{B}})$$

See van Hasteren & Levin 2010

The Observations

- The extended PPTA data set
- Three questions
- Does a GW memory signal exist in the PPTA data sets?
- What is the size of the maximum possible GW memory event that could have taken place?
- What are the astrophysical implications of our upper bounds on such events.



Algorithm for searching and limiting GWM

- Searching

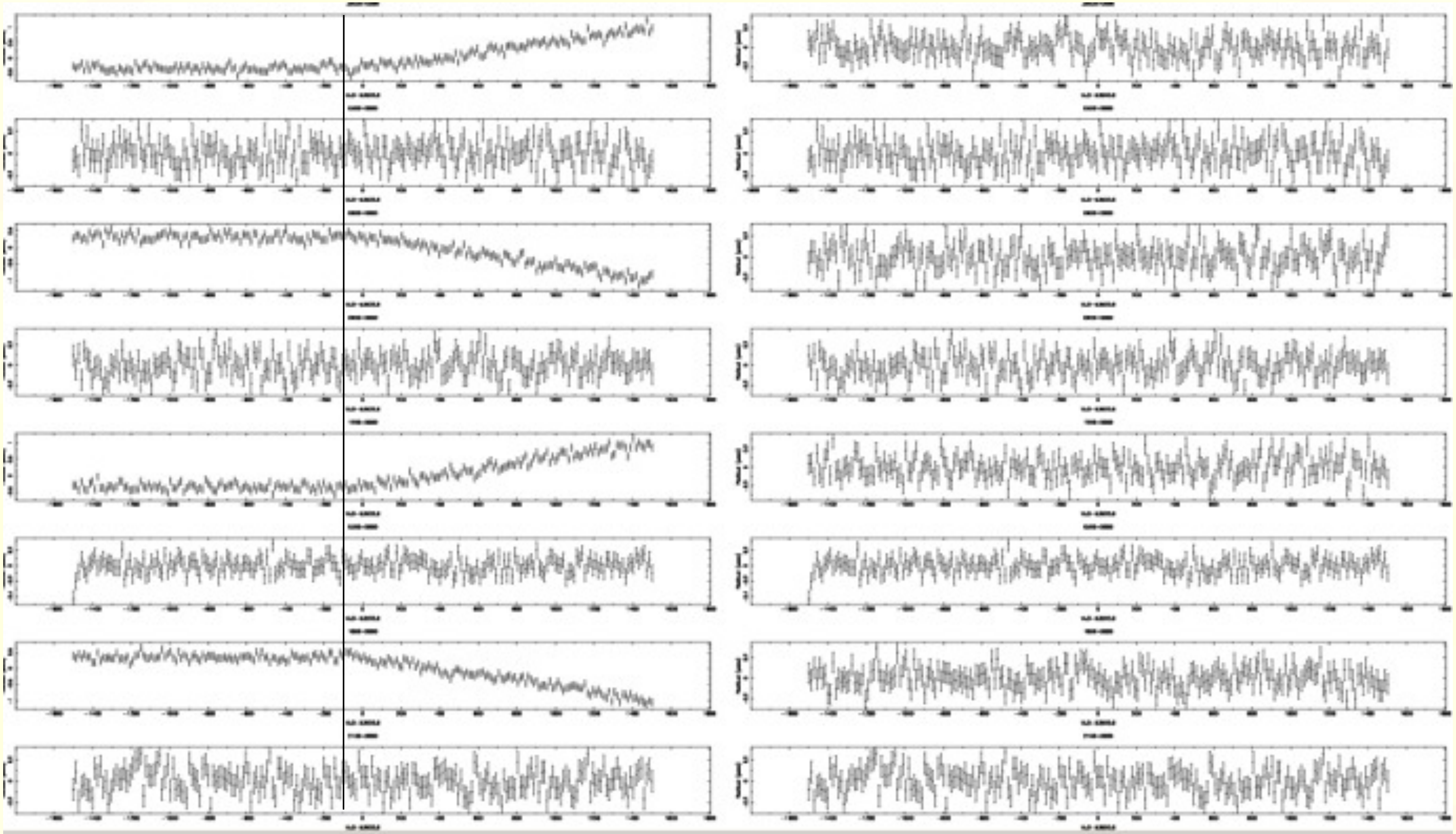
1. Incorporate the residual induced by GWM signal into TEMPO2
1. Set the global par file and, fit for the amplitude of GWM
2. The detection significance is defined as
   S=gwm_amp/gwm_amp_err
3. If S larger than the detection threshold, we make a detection

- Limiting

1. Add a GWM signal into the data set
2. Get a new significance value (S_i)
3. Compare it with the original significance (S_real)
4. Repeat it 100 times
5. Find a amplitude of GWM signal which can make 95%
   S_i > S_real

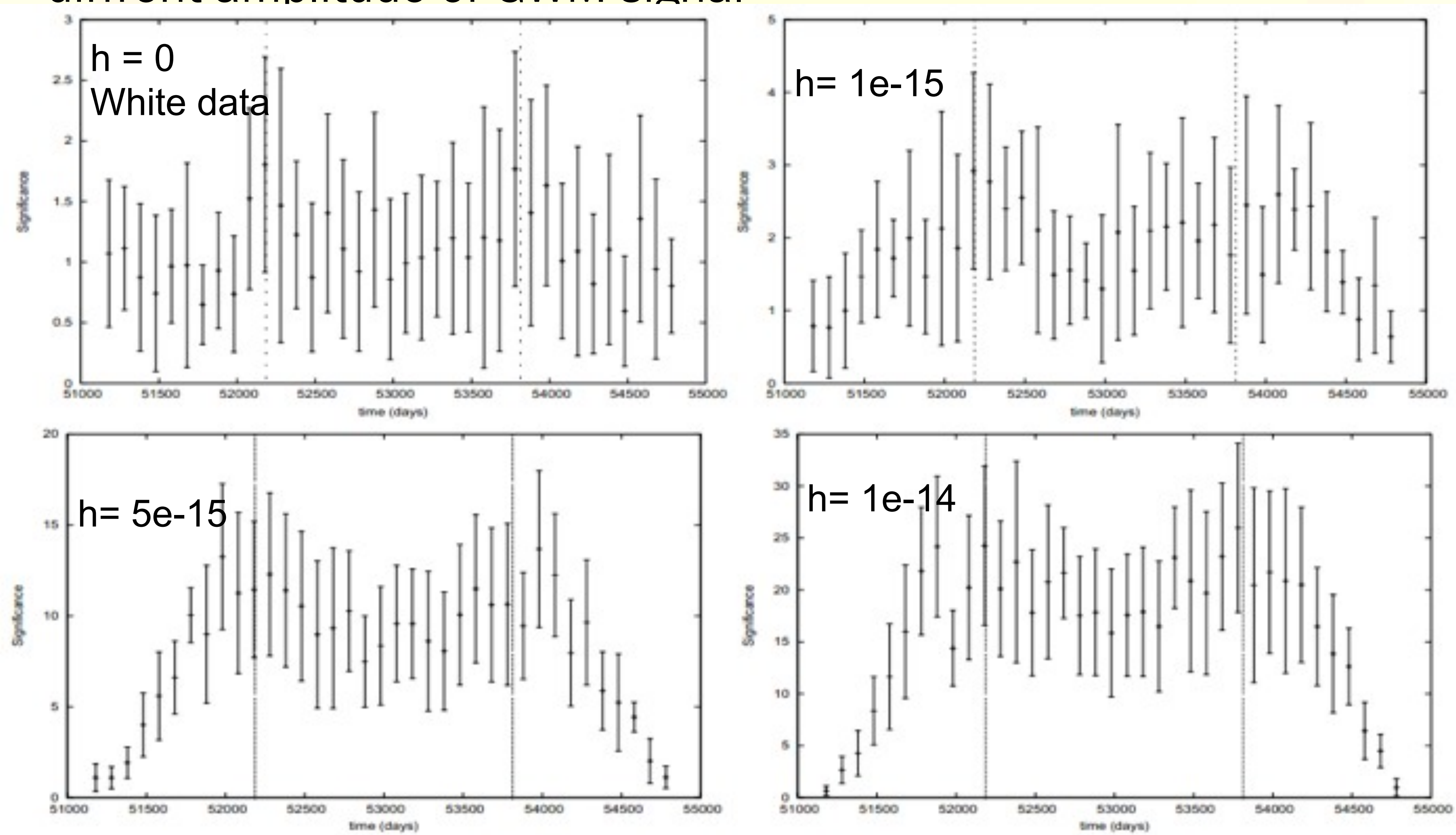
Algorithm for searching and limiting GWM

- Put the pulsar in a ring on the equator, the GWM soure in the north pole



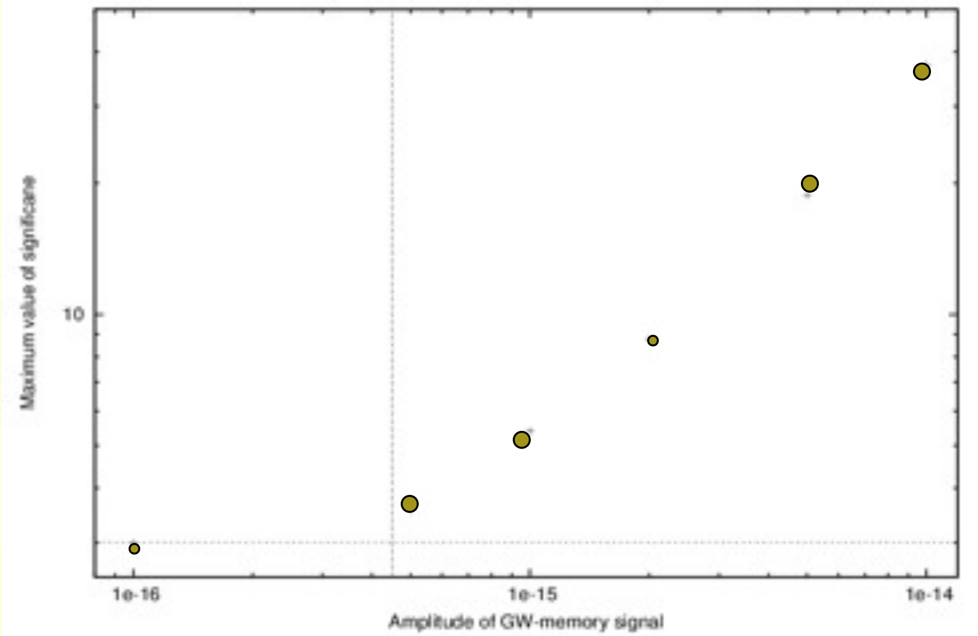
Algorithm for searching and limiting GWM

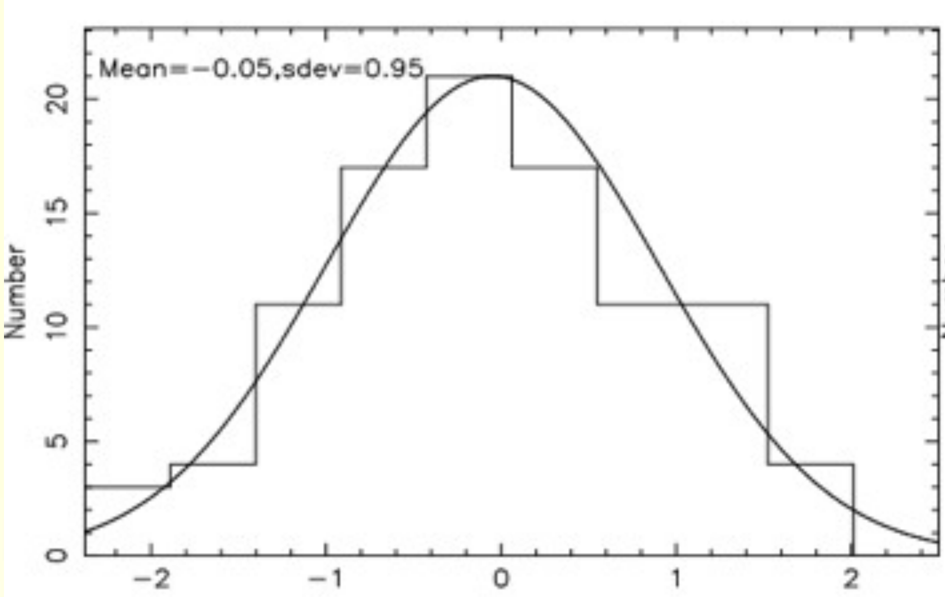
The detection significance as a function of GWM event epoch for diffrent amplitude of GWM signal

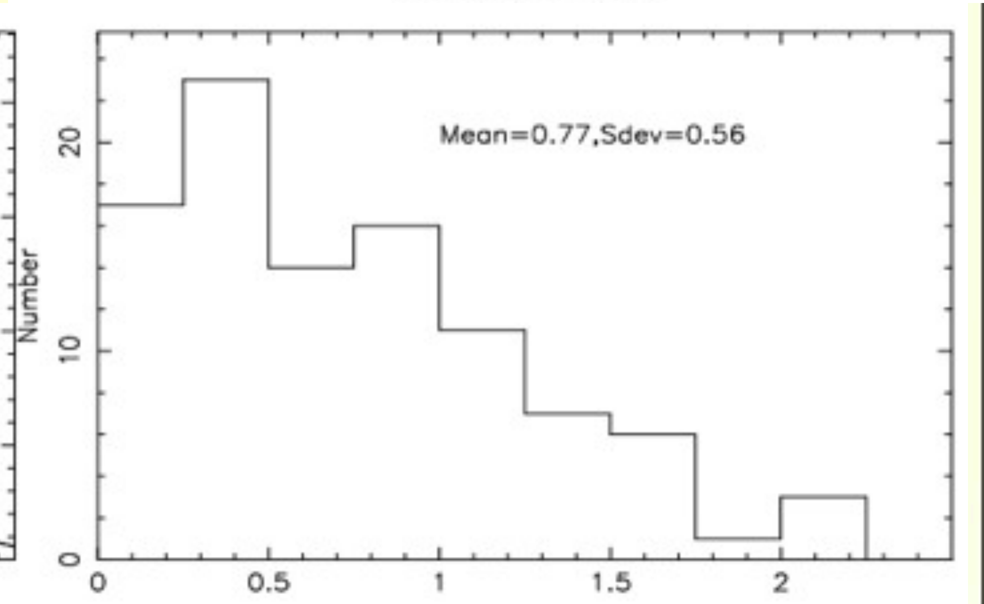


Algorithm for searching and limiting GWM

- The maximum significance for a certain gwm magnitude
- The distribution of S at a certain epoch for 100 simulations of white data
- The distribution of |S| at a certain epoch for 100 simulations

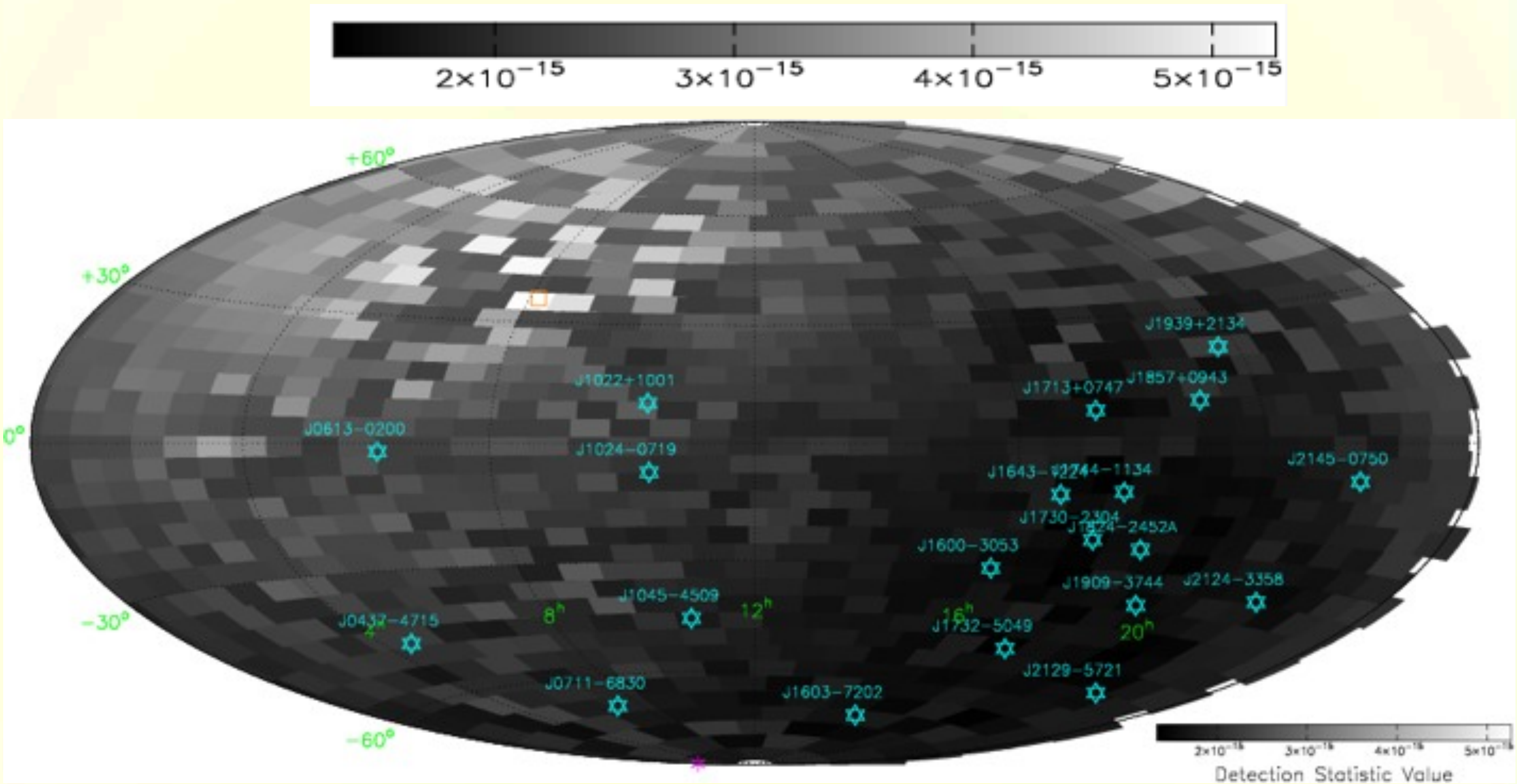






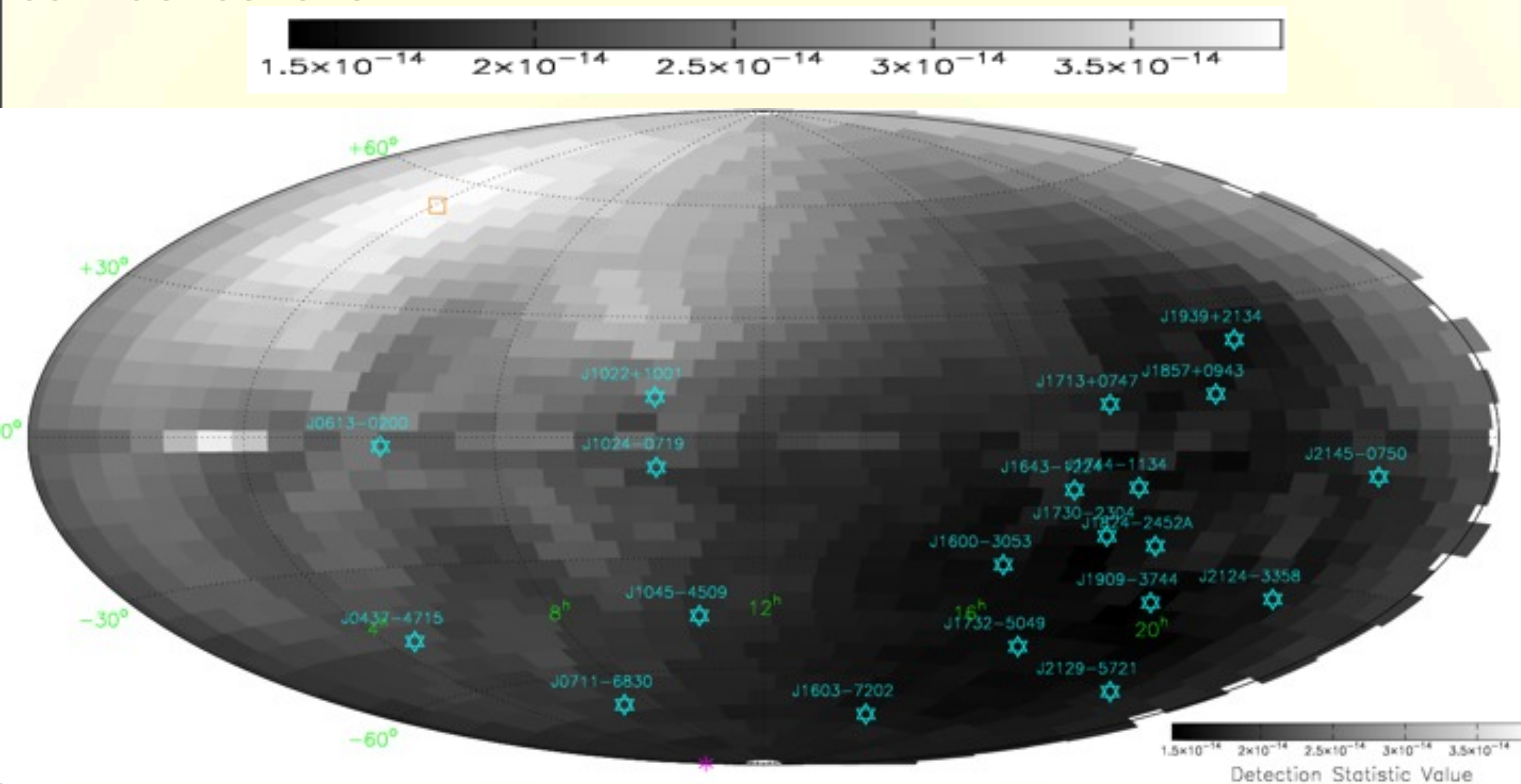
Algorithm for searching and limiting GWM

- 100 ns rms level for each pulsar
- The GWM ampulitude which can make a detection at 95% confidence level



Algorithm for searching and limiting GWM

- Realistic rms level
- The GWM ampulitude which make a detection at 95% confidence level



Prospect

- Apply the algorithm to extension PPTA data set
- Search/limit GWM signal with extension PPTA data set
- Algorithm for searching and limiting a glitch
- Search for glitches or put a upper limit on the size of the glitches in young pulsars from PPTA pulsars, young pulsars observed by Parkes and Nanshan

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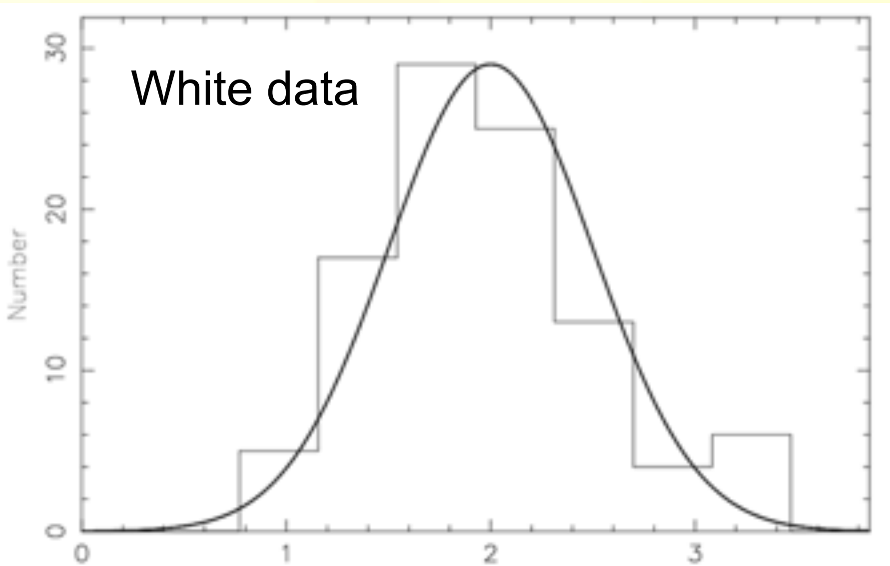
Thank you!

Algorithm for searching and limiting a normal glitch

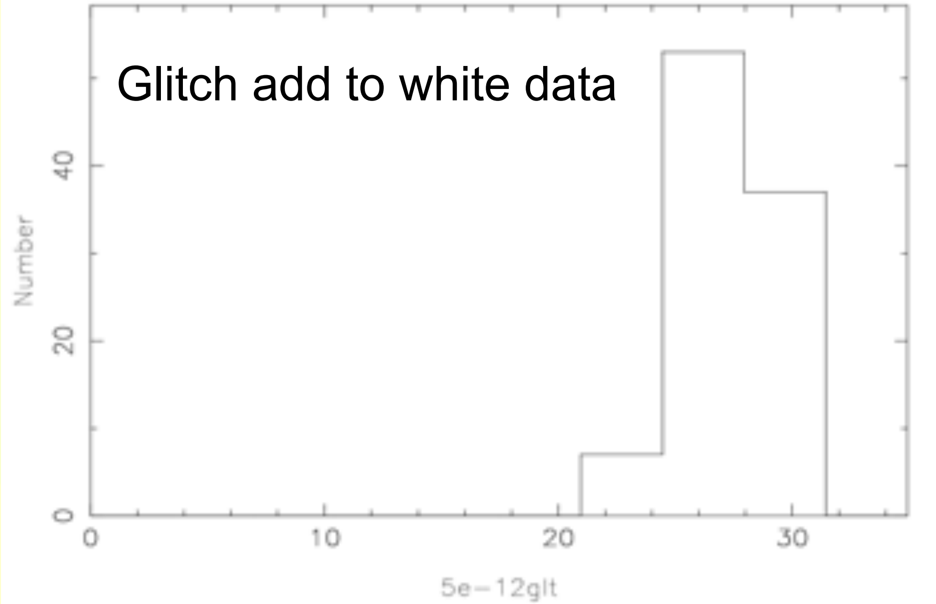
- Simulating timing residuals only contain white noise, regular sampling, same error bars ,100ns rms, 5 years
- Fitting for a glitch at different times in the data sets and calculating a statistic, find the maxium value, S=|GLF0/GLF0_err|, Repeat it 100 times
- Add a glitch at the middle of the observations into the white timing residuals,calculating the statistic, find the maximum value, Repeat it 100 times

Distribution of S_max for 100 white data



S_max

Distribution of S_max for glitch size of 5e-12 Hz

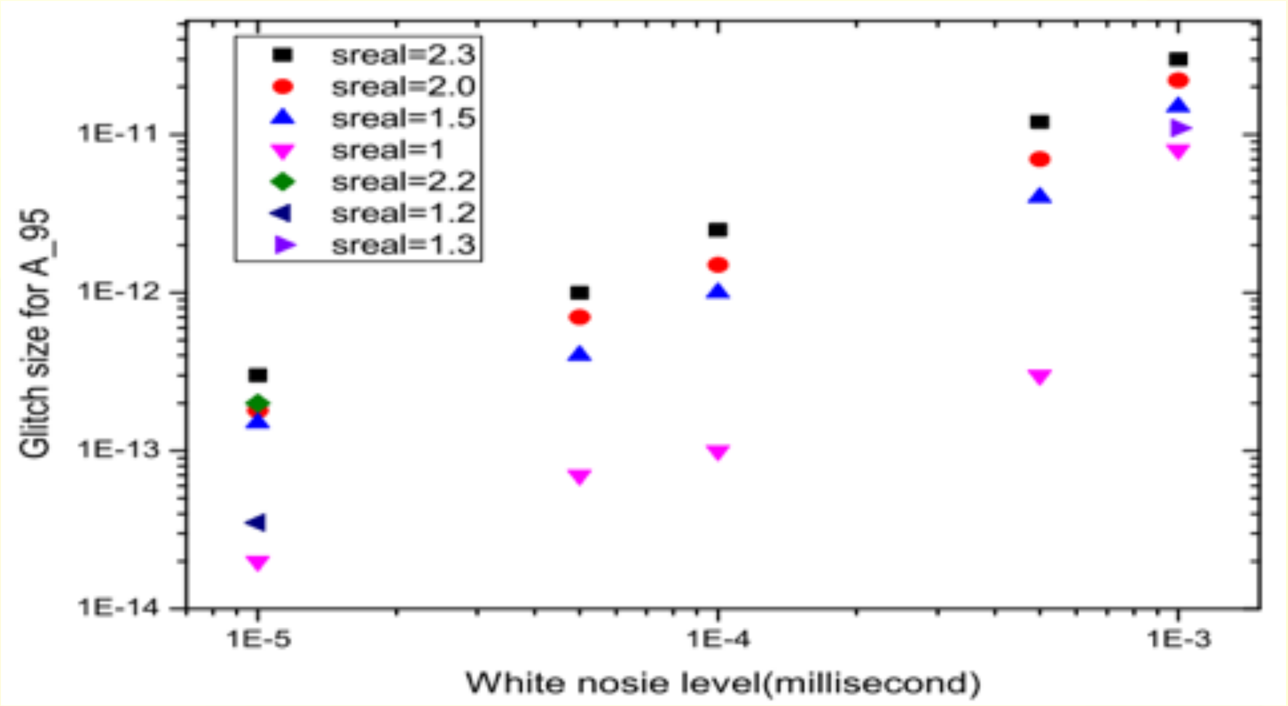


S_max

Algorithm for searching and limiting a normal glitch

- Simulate a white data set, pretend it is "real" data, calculate the statistic S_real
- Add a glitch of a given size at a random position in the data set, get the statistic, S_i repeat it 100 times
- Change the glitch size, find the glitch size which make

  95% percents S_i > S_real, record it as A_95
- Try different white noise levels



Algorithm for searching and limiting a normal glitch

- Add red noise (GW background) into the simulated white timing residuals
- Fit for the glitch,turn off the fitting of GLF0, get the covariance function with the Cholesky method; Then fit for the glitch by using the covariance function. Repeat it 3 times
- The significance will increase a lot if the glitch epoch is right