Pulsar Stability
(and
A New Limit on the GWB* from Pulsar Timing)

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*: GWB = Gravitational Wave Background
Outline

• High precision timing of MSPs*
• Long-term timing stability
• Simple GWB limit technique
• Conclusions

*: MSP = Milli-Second Pulsar
Quick Basics of Pulsar Timing

- Basic Method:
  - Theoretical Model
    - Actual Pulse Arrival Time
  = Timing **Residual**

\[
T_{\text{th}} = vt + \frac{1}{2} \dot{v}t^2 + D \int_0^d n_e dl - \frac{1}{c} (\hat{r} \cdot \hat{s}) + \frac{V_T^2 t^2}{2cd} - \frac{(\hat{r} \times \hat{s})^2}{2cd} + \ldots
\]
Precision Timing
State-of-the-Art

- PSR J0437–4715
- 10 years
- 4 instruments
- 200 ns rms
- Highest precision over decade!

(Verbiest et al., 2008)
Long–term Stability of MSPs

GWB sensitivity requires:

(Jenet et al., 2005)

- High timing precision (\(\sim 10^2\) ns)
- Long observing campaigns (\(\sim 10^1\) yrs)

⇒ Highly stable MSPs
Expected GWB signature

LOW frequency

LOW strain (strength)

(Figure courtesy of G. Hobbs)
Stability: Observations

• 12 years (avg.) on 20 PPTA* pulsars

*: PPTA = Parkes Pulsar Timing Array
Stability: Examples: 1824

PSR J1824–2452
(in Globular Cluster M28)

Residual

Time →

Power

(low)  Frequency  (high)
Stability: Examples: 1909

PSR J1909-3744:
158 ns over 5 yrs
Stability: Observations

- 12 years (avg.) on 20 PPTA* pulsars
  - 2: clear timing noise (J1939+2134, J1824–2452)
  - 2: some evidence for timing noise (J0613–0200, J1024–0719)
  - 12 remaining: white noise, μs–level rms
  - average: 2.2 μs rms

*: PPTA = Parkes Pulsar Timing Array
Stability: Conclusion & Prospects

• Mostly stable, but high noise levels

Detection prospects look good, provided:

• New instruments \(\text{(bandwidth, resolution)}\)
• New calibration methods
• New software
• New pulsars \(\text{(surveys)}\)
• Collaboration \(\text{(more, bigger telescopes)}\)
PTAs need to “see” the GWs

PSR J0837+0719
True Residuals

PSR J1939+2134
True Residuals + simulated GWB

Simulated GWB
GWB vs. Pulsar Spectrum

PSR J0437-4715

GWB
A Very Simple GWB Limit

- Spectrum of Pulsar Residuals: $P_{\text{PSR}}(f)$

- Monte-Carlo GWB Spectrum: $P_{\text{GWB}}(A,f)$

- Statistic: $S = \sum (W(f) \times P(f))$

- Bound: amplitude for which $S_{\text{GWB}} > S_{\text{PSR}}$, 95% of the time
Previous Limits in Literature

- Thorsett & Dewey, Ph. Rev. D, 1996
- McHugh et al., Ph. Rev. D, 1996
Earlier Limit Problems

**Then**

- No GWB simulations – all analytic
  - Fitting, jumps & sampling effects
  - Hard Statistics

- White residuals required (Jenet et al., 2006)

**Now**

- GWB simulation software (Hobbs et al., 2008)
  - Monte-Carlo simulations

- Red noise allowed
Details to be Worked Out

- Precise weighting (i.e. combination of frequencies)
- Combination of Pulsars
- Spectral leakage
- Steep spectra
No (New) Limit
Conclusions

• MSPs are intrinsically stable
• Limits are useful too
• Promising new limit coming soon
Gravitational Wave Effect

## Results (Summary)

<table>
<thead>
<tr>
<th>No.</th>
<th>JName</th>
<th>rms</th>
<th>Timespan</th>
<th>Npts</th>
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<tr>
<td>1</td>
<td>J1909-3744</td>
<td>167 ns</td>
<td>5.2 yrs</td>
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<td>199 ns</td>
<td>9.9 yrs</td>
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<td>J1939+2134</td>
<td>20.1 ns</td>
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GWB vs. Pulsar Spectrum

PSR J0437-4715

Frequency

GWB
Stability: Examples: 1713

PSR J1713+0747:
362 ns over 14 yrs