Timing Noise

• Timing noise pervades timing residuals of most young/middle-aged pulsars

• Recent review by Hobbs, Lyne & Kramer 2010
  – Using 76-m Lovell Telescope at Jodrell Bank
  – Observations of ~700 pulsars covering 10-40 yrs
Timing Noise

• For long, thought to be random and non-deterministic
• For youngest pulsars, not necessarily so
• e.g. B1800-21 – three 2000-day sequences, following glitches

• Clearly repeating pattern
• No detectable profile changes
• Due to physics of the glitch phenomenon and the interior of the NS (Espinosa et al. in prep.)
• Non-random and deterministic
Timing Noise

- Prevalent also in middle-aged non-glitching pulsars
- Smooth changes in timing residuals and rotation frequency
- Often asymmetric – peaks and troughs different curvature
- Often quasi-periodic
PSR B1931+24

- Reported by Kramer et al. (2006)
- Periodically nulling pulsar
- On for 1 week, off for 1 month
PSR B1931+24

- Reported by Kramer et al. (2006)
- Periodically nulling pulsar
- ON for ~1 week, OFF for ~1 month
- Also has high timing noise

Increase in slow-down rate during ‘ON’ state:

\[ \frac{f_{1\text{ON}}}{f_{1\text{OFF}}} = 1.5 \pm 0.1 \]

Increase in magnetospheric currents causes
- Increase in emission
- Increase in slowdown rate
PSR J1832+0029

- Discovered in PMPS
- ‘ON’ state ~1400 days
- ‘OFF’ state ~700 days
- Increase in slow-down rate during ‘ON’ state:

  \[ \frac{f_{1_{\text{ON}}}}{f_{1_{\text{OFF}}}} = 1.7 \pm 0.1 \]

PSR J1841-0500

0.9-sec pulsar recently reported by Camilo et al. (2011)

ON >300 days
OFF ~600 days

Increase in slow-down rate during ‘ON’ state:
\[ f_{1_{\text{ON}}}/f_{1_{\text{OFF}}} = 2.5 \pm 0.2 \]

Recently switched ‘OFF’ again
Timing Noise

- Slow-down rate $f_1$ often shows periodicities clearly.
- On long timescales does not look noise-like.
- Variations bounded by well-defined low and high values.
Timing Noise

- Magnitude of noise
  \[ \frac{\Delta f_1}{f_1} \approx 1\% \]
Pulse Shape Changes

- Studied pulsars with largest fractional slow-down rate changes
- Found many with changes in shape
- Six most obvious:
  
  a) J2043+2740
  b) B2035+36
  c) B1828–11
  d) B0740–28
  e) B1540–06
  f) B1822–09

Lyne et al 2010. Science, 329,408
Pulse Shape Changes

- Chose simple “shape parameters” to distinguish
- Averaged values over length of timing fits
- High degree of correlation with slowdown rate $f_1$:

Lyne et al 2010. Science, 329, 408
Pulse Shape Changes

- Chose simple “shape parameters” to distinguish
- Averaged values over length of timing fits
- High degree of correlation with slow-down rate f1:

Lyne et al 2010. Science, 329, 408
Other Pulsars

PSR B0105+65

PSR B0919+06

PSR B1642-03
Nature of the Switching

- Switching between \(~2\) states
- Statistics change slowly
- Shapes very under-sampled

Lyne et al 2010. Science, 329,408
Nature of the Switching - B1828-11

~8-hour observations
Nature of the Switching – B1828-11

Pulse shape change also associated with large flux density change
Mode Changing

• These effects are classical mode changing first seen by Backer et al (1970) in B1237+25

• Now known in many pulsars e.g. J1326-6700 (Wang et al. 2007)
Mode Changing

- We see that the statistics are modulated on typical timescales of months or years.

- Such variations in statistics of mode-changing have not been studied previously.

- Another example – J2047+5029
PSR J2047+5029

- Discovered in ~2006 by Janssen et al (2009) at WSRT in the 8gr8 survey
- 0.45-sec solitary pulsar
- DM=108 cm$^{-3}$ pc
- Char. age = 1.7 My

- In 2009, observed at Jodrell Bank, but with different profile

Janssen et al. (in prep)
PSR J2047+5029

- This year it changed back

21 Dec 2011

15 Apr 2012
PSR J2047+5029

- Interpulse constant
- Main Pulse brightens by x10 in Normal mode
- Normal-mode spin-down rate is greater than Abnormal by $\Delta f_1/f_1 \sim 3.0\%$
- Particles increase both emission and slowdown rate

Janssen et al. (in prep)
## f1 and Profile Changes in non-glitching PSRs

<table>
<thead>
<tr>
<th>PULSAR</th>
<th>$\Delta f_1/f_1$ (%)</th>
<th>Profile Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1841-0500</td>
<td>150</td>
<td>Deep null</td>
</tr>
<tr>
<td>J1832-0029</td>
<td>70</td>
<td>Deep null</td>
</tr>
<tr>
<td>B1931+24</td>
<td>50</td>
<td>Deep null</td>
</tr>
<tr>
<td>B2035+36</td>
<td>13.3</td>
<td>28% change $W_{eq}$</td>
</tr>
<tr>
<td>B1740-03</td>
<td>12.7</td>
<td>70% change component ratio</td>
</tr>
<tr>
<td>B0105+65</td>
<td>11.4</td>
<td>30% change $W_{eq}$</td>
</tr>
<tr>
<td>B1903+07</td>
<td>6.8</td>
<td>10% change $W_{10}$</td>
</tr>
<tr>
<td>J2043+2740</td>
<td>5.9</td>
<td>100% change $W_{50}$</td>
</tr>
<tr>
<td>B1822-09</td>
<td>3.3</td>
<td>100% change precursor/interpulse</td>
</tr>
<tr>
<td>J2047+5029</td>
<td>3.0</td>
<td>10x change main pulse</td>
</tr>
<tr>
<td>B1642-03</td>
<td>2.5</td>
<td>20% change core/cone</td>
</tr>
<tr>
<td>B1540-06</td>
<td>1.7</td>
<td>12% change $W_{10}$</td>
</tr>
<tr>
<td>B1828-11</td>
<td>0.71</td>
<td>100% change $W_{10}$</td>
</tr>
<tr>
<td>B1826-17</td>
<td>0.68</td>
<td>10% change core/cone</td>
</tr>
<tr>
<td>B0919+06</td>
<td>0.68</td>
<td>30% change component ratio</td>
</tr>
<tr>
<td>B0740-28</td>
<td>0.66</td>
<td>20% change $W_{75}$</td>
</tr>
</tbody>
</table>
Relationship between Nulling and Mode Changing

- Nulling may be an extreme form of Mode Changing
- Both are switched phenomena with a similar large range of timescales
- Both influence the spin-down rate
- One telescope’s nulling pulsar may be a larger telescope’s mode changer!
PSR J1853+0505

Nulling or Mode-changing?
PSR B0826-34

Nulling or Mode-changing?

Esamdin et al (2005)
CONCLUSIONS

• Pulsar magnetospheres switch between small number of discrete states, usually two

• Changes in current flows cause changes in emission properties and slow-down rate
  – Large f1 associated with enhanced core emission

• Origin of the quasi-periodicities that modulate statistics unknown, possibly free precession?

• Why discrete states?
CONCLUSIONS

• These phenomena are widespread
  • The pulsars analysed are just the most timing-noisy and have the highest SNR

• These events represent major, instantaneous changes in the pulsars’ energy budgets and offer a new opportunity to study both the radiation and spin-down physics.

• Timing Noise is potentially predictable by determination of f1 from monitoring pulse shapes