Recent Radio Observations of Pulsars

R. N. Manchester

Australia Telescope National Facility, CSIRO Sydney Australia

Summary

• A pulsar census
• Recent pulsar surveys
• Pulse modulation and drifting subpulses
• Giant pulses from young and old pulsars
• Radio pulses from a magnetar
• Mean pulse polarisation - kicks and velocities
Spin-Powered Pulsars: A Census

- Number of known pulsars: 1765
- Number of millisecond pulsars: 170
- Number of binary pulsars: 131
- Number of AXPs: 12
- Number of pulsars in globular clusters: 99*
- Number of extragalactic pulsars: 20

* Total known: 129 in 24 clusters (Paulo Freire’s web page)

Data from ATNF Pulsar Catalogue, V1.25 (www.atnf.csiro.au/research/pulsar/psrcat; Manchester et al. 2005)
Parkes Multibeam Pulsar Surveys

- More than 880 pulsars discovered with multibeam system.
- The Parkes Multibeam Pulsar Survey (an international collaboration with UK, Italy, USA, Canada and Australia) has found ~760 of these (including RRATs).
- High-latitude surveys have found ~120 pulsars including 15 MSPs
- 14 pulsars found in Magellanic Clouds
**Parkes Multibeam Pulsar Survey**

- Covers strip along Galactic plane, -100° < l < 50°, |b| < 5°
- Central frequency 1374 MHz, bandwidth 288 MHz, 96 channels/poln/beam
- Sampling interval 250 μs, time/pointing 35 min, 3080 pointings
- Survey observations commenced 1997, completed 2003
- Processed on work-station clusters at ATNF, JBO and McGill
- 1015 pulsars detected
- At least 18 months of timing data obtained for each pulsar

**Principal papers:**

I: Manchester et al., MNRAS, 328, 17 (2001)
   System and survey description, 100 pulsars

    120 pulsars, preliminary population statistics

    200 pulsars, young pulsars and γ-ray sources

    180 pulsars, 281 previously known pulsars

   Reprocessing methods, 17 binary/MSPs

VI: Lorimer et al., MNRAS, in press (2006a)
   142 pulsars, Galactic population and evolution
Galactic Distribution of Pulsars

• Number of potentially detectable pulsars in Galaxy $\sim 30,000 \pm 1100$

• With beaming correction $\sim 150,000$

• Derived radial distribution very dependent on Galactic electron density model

• $z$ scale height $\sim 330$ pc (Model S), $\sim 180$ pc (Model C) - larger scale height more consistent with other results

• Luminosity function slope -0.6 (S) or -0.8 (C)

• Birthrate of potentially observable pulsars $L > 0.1$ mJy kpc$^2$ $\sim 0.34 \pm 0.05$ pulsars/century

• With beaming correction $\sim 1.3 /$century

(Lorimer et al. 2006a)
The Parkes High-Latitude Multibeam Survey

• $220^\circ < l < 260^\circ$, $|b| < 60^\circ$
• Samp. int. 125 ms, obs. time 4 min
• 6456 pointings

• 18 discoveries, 42 pulsars detected
• 4 MSPs, including the double pulsar! J0737-3039A/B

(Burgay et al. 2006)
Galactic Distribution of Pulsars
Parkes Multibeam Surveys: P vs $\dot{P}$

- New sample of young, high-B, long-period pulsars
- Large increase in sample of mildly recycled binary pulsars
- Three new double-neutron-star systems and one double pulsar!
The PALFA Survey - A multibeam survey at Arecibo

- 7-beams, 1.4 GHz, 100 MHz (300 MHz later), 256 channels
- $32^\circ < l < 77^\circ$, $168^\circ < l < 214^\circ$, $|b| < 5^\circ$
- Samp. Int. 64 $\mu$s, obs time 134 (67) s
- Preliminary analysis: 11 discoveries, 29 redetections
- Full survey: 1000 new psrs
  (~375 - Lorimer et al. 2006a)
  (Cordes et al. 2006)

PSR J1906+0746

- 144-ms pulsar in 3.98-h binary orbit
- Highly relativistic, $\omega \sim 7.6^\circ/yr$
- $m_p + m_c = 2.61 \pm 0.02 \, M_{\odot}$
- Pulsar is young! $\tau_c \sim 112$ kyr
- Companion either a massive white dwarf or a neutron star (observed pulsar is the second born)
- Coalescence time $\sim 300$ Myr

(Lorimer et al. 2006b)
Magellanic Cloud Survey

- Parkes multibeam system
- 73 (SMC), 136 (LMC) pointings
- Samp. int. 1 ms, Obs. time 2.3 h
- $S_{\text{min}} \sim 0.12 \text{ mJy}$

- 14 pulsars discovered, 12 in MC
- Total of 20 known pulsars in MC
- Luminosity function consistent with that for Galactic pulsars
- No significant $L(P), L(\tau_c)$
  (Manchester et al. 2006)
• 600 MHz bandwidth at 2 GHz
• 5.9h obs with 82 μs sampling
• $S_{\text{min}} \sim 15 \mu\text{Jy}$
• 31 pulsars discovered!! 33 total in cluster (www.naic.edu/~pfreire/GCpsr.html)
• Two eccentric relativistic binaries; N-star $\sim 1.7 \, M_\odot$?

• PSR J1748-2446ad - fastest known pulsar!
• $P = 1.3959 \, \text{ms}$, $f_0 = 716.3 \, \text{Hz}$, $S_{2000} \sim 80 \mu\text{Jy}$
• Binary, circular orbit, $P_b = 1.09 \, \text{d}$
• Eclipsed for $\sim 40\%$ of orbit
• $m_c > 0.14 \, M_\odot$ (Hessels et al. 2006)
GBT Search of Globular Cluster Terzan 5

- 600 MHz bandwidth at 2 GHz

Table 2. The 10 fastest spinning known radio pulsars. Data compiled from the Australia Telescope National Facility pulsar database (33).

<table>
<thead>
<tr>
<th>Pulsar</th>
<th>Spin frequency (Hz)</th>
<th>( P_b ) (days)</th>
<th>( M_{2,\text{min}} (M_\odot) )</th>
<th>Eclipse fraction</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1748–2446ad</td>
<td>716.358</td>
<td>1.0944</td>
<td>0.14</td>
<td>0.4</td>
<td>Terzan 5</td>
</tr>
<tr>
<td>B1937+21</td>
<td>641.931</td>
<td>isolated</td>
<td></td>
<td></td>
<td>Galaxy</td>
</tr>
<tr>
<td>B1957+20</td>
<td>622.123</td>
<td>0.3819</td>
<td>0.021</td>
<td>0.1</td>
<td>Galaxy</td>
</tr>
<tr>
<td>J1748–2446O</td>
<td>596.435</td>
<td>0.2595</td>
<td>0.035</td>
<td>0.05</td>
<td>Terzan 5</td>
</tr>
<tr>
<td>J1748–2446P</td>
<td>578.496</td>
<td>0.3626</td>
<td>0.37</td>
<td>0.4</td>
<td>Terzan 5</td>
</tr>
<tr>
<td>J1843–1113</td>
<td>541.812</td>
<td>isolated</td>
<td></td>
<td></td>
<td>Galaxy</td>
</tr>
<tr>
<td>J0034–0534</td>
<td>532.714</td>
<td>1.5892</td>
<td>0.14</td>
<td>0</td>
<td>Galaxy</td>
</tr>
<tr>
<td>J1748–2446Y</td>
<td>488.243</td>
<td>1.17</td>
<td>0.14</td>
<td>0</td>
<td>Terzan 5</td>
</tr>
<tr>
<td>J1748–2446V</td>
<td>482.507</td>
<td>0.5036</td>
<td>0.12</td>
<td>0</td>
<td>Terzan 5</td>
</tr>
<tr>
<td>B0021–72J</td>
<td>476.048</td>
<td>0.1206</td>
<td>0.020</td>
<td>0.1*</td>
<td>47 Tucanae</td>
</tr>
</tbody>
</table>

(Hessels et al. 2006)
Pulsar Nulling

• Parkes observations of 23 pulsars, mostly from PM survey
• Large null fractions (up to 96%) - mostly long-period pulsars
• Nulls often associated with mode changing (Wang et al. 2006)
PSR B0826-34

- $P = 1.848$ s, pulsed emission across whole of pulse period
- In “null” state $\sim 80\%$ of time
- 5-6 drift bands across profile, variable drift rate with reversals
- Weak emission in “null” phase, $\sim 2\%$ of “on” flux density
- Different pulse profile in “null” phase

*Null is really a mode change!*

(Esamdin et al. 2005)
Nulls as Mode Changes

- Parkes observation of PSR B1322-66 (J1326-6700)
- 2 hours at 1.4 GHz
- Individual pulses recorded
- Frequent short “nulls” observed
- During “null”, new component appears at leading edge of pulse
- Highly variable in both phase and amplitude

Nulls and mode changes represent a sudden transition between two (occasionally more) quasi-stable states of current flow in the magnetosphere

(Wang et al. 2006)
PSR B1931+24 - An extreme nuller

- Quasi-periodic nulls: on for 5-10 d, off for 25-35 d
- **Period derivative is \(~35\%\) smaller when in null state!**
- Implies cessation of braking by current with G-J density
- Direct observation of current responsible for observed pulses

(Kramer et al. 2006)
Pulse Modulation

- Extensive survey of pulse modulation properties at Westerbork - 187 pulsars
- Observations at 1.4 GHz, 80 MHz bw
- Modulation indices, longitude-resolved and 2D fluctuation spectra computed
- 42 new cases of drifting subpulses

At least 60% of all pulsars show evidence for drifting behaviour
“Coherent” drifters have large characteristic age, but drifting seen over most of $P - \dot{P}$ diagram

(Weltevrede et al. 2006a)
• “Drifting subpulses” observed in B pulse emission in leading bright phase, $P_2 \sim P_A$
• Drift rate of 0.196 cycles/period
• Ratio of pulsar barycentric periods: $P_B/P_A = 122.182$
• Doppler shift from varying separation of A & B - at orbital longitude 205°, predicted beat frequency $\sim 0.196$ cycles/period, exactly as observed!
• Suggests that modulation is due to impact of A’s magnetic-dipole radiation field on B’s magnetosphere, rather than A pulses or wind
• Mechanism not clear - modulation of beam direction or emission intensity?

(McLaughlin et al. 2004)
Giant Pulses

Intense narrow pulses with a pulse energy many times that of an average pulse - characterised by a power-law distribution of pulse energies.

First observed in the Crab pulsar - discovered through its giant pulses!

- Arecibo observations at 5.5 GHz
- Bandwidth 0.5 GHz gives 2 ns resolution
- Flux density > 1000 Jy implies $T_b > 10^{37}$ K!
- Highly variable polarisation
- Suggests emission from plasma turbulence on scales ~ 1 m

(Hankins et al. 2003)
Crab Giant Pulses

- 600 MHz observations, Kalyazin 64m
- All pulses from the main pulse and interpulse are giant
- Precursor has no giant pulses
- Giants have high circular polarisation, typically $> 40\%$

(Popov et al. 2006)

- Effelsberg, 8.3 GHz, 6.7 hours
- Giant pulses from HF components (Moffet & Hankins 1996) as well as MP and IP

(Jessner et al. 2005)
Giant Pulses from Millisecond Pulsars

- Giant pulses seen from several MSPs with high $B_{LC}$
- Most also have pulsed non-thermal emission at X-ray energies
- Giant pulses occur at phase of X-ray emission

PSR J0218+4232

(Cusumano et al. 2003)

( Knight et al. 2006, Kuiper et al. 2004, Rutledge et al. 2004)
“Giant” Pulses from Other Pulsars

- Some pulsars occasionally emit very strong pulses - few 100x mean flux density
- Emitted at different phases across pulse profile, pulse widths ~ ms
- Not power-law distribution of pulse energies
- Not associated with non-thermal X-ray emission
- These pulsars do not have high $B_{\text{LC}}$

Not the same phenomenon as the giant pulses observed in the Crab and MSPs

- Extreme examples of normal subpulse modulation
- Likely to be same population as RRATs

(Weltevrede et al. 2006b)
(Kuzmin & Ershov 2004)
Transient Pulsed Radio Emission from a Magnetar

- AXP XTE J1810-197 - 2003 outburst in which X-ray luminosity increased by ~100
- X-ray pulsations with P = 5.54 s observed
- Detected as a radio source at VLA, increasing and variable flux density: 5 - 10 mJy at 1.4 GHz (Halpern et al. 2005)
- Within PM survey area, not detected in two obs. in 1997, 1998, S_{1.4} < 0.4 mJy
- Observed in March 2006 at Parkes (Camilo et al. 2006)

- **Pulsar detected!**
  - S_{1.4} ~ 6 mJy
  - Very unusual flat spectrum - individual pulses detected in GBT observations at 42 GHz!

Earlier unconfirmed detections (e.g. Malofeev et al 2005) accounted for by transient and highly variable nature of pulsed emission?
Rotation Axis - Velocity Correlation

- X-ray observations of Vela pulsar revealed toroidal structures which defined direction of rotation axis - within 10° of proper motion direction (Helfand et al. 2001)
- Similar X-ray tori observed in several other young pulsars with similar alignment (Ng & Romani 2004)
- In principle can use observed linear position angle (PA) of pulsar radio emission with rotating-vector model (RVM) to define direction of rotation axis on sky
- Complicated by presence of orthogonal modes and non-RVM PA curves

- Parkes observations of 25 pulsars at 1.4 GHz
- Carefully calibrated and corrected for interstellar Faraday rotation

(Johnston et al. 2005)
Rotation Axis - Velocity Correlation (ctd)

- Of 25 observed pulsars, 10 have offset between velocity vector and symmetry point of PA variation of $< 10^\circ$ or $> 80^\circ$
- Simulations with parallel or perpendicular PA agree well with observed distribution

(Johnston et al. 2005)

Similar results from archival polarisation data (Wang et al. 2006)

Supports notion of alignment between rotation axis and velocity: kick-induced spin? (e.g., Spruit & Phinney 1998)
Mean Pulse Polarisation

- Parkes observations at 1.4 and 3.1GHz
- Dual frequency obs of 17 pulsars, 14 young pulsars ($\tau_c < 75$ kyr)

(Karastergiou & Johnston 2006)

- Linear polarisation very high for young pulsars, generally > 75%
- PA variations generally the same at the two frequencies - no rotation in magnetosphere
- Patchy cones - wide beams!

(Johnston & Weisberg 2006)
Thank you for your attention!
Orbital Modulation of PSR J0737-3039B

Secular changes are observed!

• Bright phases are becoming shorter and more widely separated
• Pulse profile is changing from double to single

(Burgay et al. 2005)