Searching for pulsars in globular clusters

Sander ter Veen (LOFAR PWG)
ASTRON
Why do we study pulsars?

Precise clocks + Point masses
Study orbital parameters in binary and triple systems (test GR)
Study interstellar matter (dispersion, scattering)
Equation of State of dense matter (quarkstars?)
Holy grail: NS – BH binary
Gravitational waves
Equation of State

Fastest pulsar **PSR J1748-2446ad**
716 Hz, Hessels et al. Science 2006

Demorest et al. Nature 2010
Globular clusters

- Dense group of stars ($10^3$ – $10^6$ / pc$^3$)
- Old, most stars evolved
- Many binary interactions / systems
- Many millisecond pulsars (124/144)
Highlights GC pulsars

• Fastest pulsar known (716 Hz, PSR J1748-2446ad, Hessels et al. 2006)

• Triple system (WD+ Planet, Lyne et al. 1988)

• Eclipsing binaries with low mass companion

• Intra-cluster ionized gas (from DM, Freire et al. 2001)

  – Similar with LOFAR: Measure Magnetic field?
Pulsar searches

• Search for dispersed, repeated pulses with unknown:
  – Dispersion Measure (DM)
  – Period
  – Period derivative
  – Orbital parameters (binary systems)
## M13 known pulsars

<table>
<thead>
<tr>
<th>Name</th>
<th>Period (ms)</th>
<th>DM (pc/cc)</th>
<th>$S_{400}$ (mJy)</th>
<th>$S_{1400}$ (mJy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1639+36A</td>
<td>10.377</td>
<td>30.36(4)</td>
<td>3</td>
<td>0.14</td>
</tr>
<tr>
<td>B1639+36B</td>
<td>3.528</td>
<td>29.5(1.5)</td>
<td></td>
<td>0.022</td>
</tr>
<tr>
<td>J1641+3627C</td>
<td>3.722</td>
<td>30.1</td>
<td></td>
<td>0.030</td>
</tr>
<tr>
<td>J1641+3627D</td>
<td>3.118</td>
<td>30.6</td>
<td></td>
<td>0.024</td>
</tr>
<tr>
<td>J1641+3627E</td>
<td>2.487</td>
<td>30.3</td>
<td></td>
<td>0.010</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Binary period</th>
<th>Semi-major axis (lt sec)</th>
<th>Minimum Mass (Solar Mass)</th>
<th>Companion type</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1639+36B</td>
<td>1.259</td>
<td>1.389</td>
<td>0.160590</td>
<td>He WD</td>
</tr>
<tr>
<td>J1641+3627D</td>
<td>0.592</td>
<td>0.924</td>
<td>0.178036</td>
<td></td>
</tr>
<tr>
<td>J1641+3627E</td>
<td>0.117</td>
<td>0.037</td>
<td>0.019532</td>
<td>Planet?</td>
</tr>
</tbody>
</table>
Search method

- Coherently dedispersed dynamic spectra on multiple DM trials (new approach!)
- Fine incoherent dedispersion
  - (DMstep=0.0005 pc/cc, Resolution 0.1 ms, Dmrange 29.0-31.0 pc/cc)
- Searching for periodicities
- Searching for binary pulsars
- Debug along the way
M13A found!

DM = 30.4305 ± 0.0005, Literature 30.36

Detected in Search Pipeline!

Other M13 pulsars not detected. Not surprising (RFI, scattering, etc.)
M13A flux

Frequency [MHz] vs. Flux [mJy]

- Hessels et al. ‘07
- Kulkarni et al. ‘91
- LOFAR measured
Flux correction on B1508+55

Correction factor: 3x
M13A flux

1.8 mJy (expected 12-18 mJy)

Spectral turnover
Pulsar candidate?
Pulsar candidate?
Best candidate

DM = 29.602, P = 5.4458 ms

Telescope: LOFAR
Epoch (topo) = 56745.17769447336
Epoch (bary) = 56745.18035049395
Tsample = 4.096e-09
Data Folded = 155189248
Data Avg = 4.08e+05
Data StdDev = 1160
Profile Bins = 128
Profile Avg = 4.947e+11
Profile StdDev = 1.277e+06

Folding Parameters
Reduced $\chi^2 = 0.985$, P(Noise) < 0.532 ($\sigma$ = 0.1σ)

Dispersion Measure (DM; pc/cm$^3$) = 29.602
P_topo (ms) = 5.44557316(13)
P_topo (s/s) = 3.4(1.9)x10^{-13}
P_topo (s/s^2) = 0.0(1.9)x10^{-16}

Binary Parameters
P_orb (s) = N/A
$a_1\sin(i)/c$ (s) = N/A
$e$ B = N/A
$\omega$ (rad) = N/A

Period = 5.44557316 (ms)
Freq = 183.635399 (Hz)
P_dot = 3.3948e-13 (s/s)

M13_L215016_Pall_320ch_DM2950.fil

26-Aug-2014
Detect other GC pulsars

Peak S/N for a 4h observation with the LOFAR core. Assuming a spectral index of -1.4

<table>
<thead>
<tr>
<th>Name</th>
<th>Globular Cluster</th>
<th>Period (ms)</th>
<th>DM (pc/cm)</th>
<th>Expected S/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2127+11A</td>
<td>M15</td>
<td>110.665</td>
<td>67.31</td>
<td>337.5</td>
</tr>
<tr>
<td>B2127+11B</td>
<td>M15</td>
<td>56.1330</td>
<td>67.69</td>
<td>118.5</td>
</tr>
<tr>
<td>B2127+11C</td>
<td>M15</td>
<td>30.5293</td>
<td>67.13</td>
<td>85.5</td>
</tr>
<tr>
<td>B1516+02A</td>
<td>M5</td>
<td>5.55359</td>
<td>30.08</td>
<td>75.8</td>
</tr>
<tr>
<td>B1516+02B</td>
<td>M5</td>
<td>7.94694</td>
<td>29.54</td>
<td>30.0</td>
</tr>
<tr>
<td>J1518+0204C</td>
<td>M5</td>
<td>2.48393</td>
<td>29.31</td>
<td>26.6</td>
</tr>
<tr>
<td>B1310+18</td>
<td>M53</td>
<td>33.1632</td>
<td>24.0</td>
<td>92</td>
</tr>
<tr>
<td>J1953+1846A</td>
<td>M71</td>
<td>4.888</td>
<td>117</td>
<td>30.3</td>
</tr>
</tbody>
</table>
Summary

• Globular clusters are an interesting place to find complex pulsar systems
• LOFAR has redetected pulsar M13A at DM=30.4305, Flux=1.8 mJy in the search pipeline
• M13A has turned over or weakened over time
• No other M13 pulsars detected
• More clusters need to be observed to see if this is a general trend