New recycled binary pulsars from the High Time Resolution Universe Pulsar Survey (HTRU) - the North

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Overview

HTRU: North and South

HTRU-North: discoveries and mass measurements

PSR J1946+3417
PSR J2045+3633
PSR J2053+4650

Prospects
THE HIGH TIME RESOLUTION UNIVERSE SURVEY

The all-sky hunt for pulsars with the Effelsberg and Parkes radio telescopes
New pulsars are always welcome!

-especially double neutron star binaries and pulsar-black hole (“holy Grail”) binaries-

Magnetars

Fast radio bursts (FRBs)

- **North:** The first all-northern-sky survey in more than 20 years!
- **South:** Find what has not been found in previous surveys

- Much higher time and frequency resolution allow us to probe deeper into the Galactic plane for short duration signals
- High-performing processing tools are available
The HTRU sky

High-lat: bright pulsars and both Galactic and extragalactic transients

Mid-lat: bright millisecond pulsars

Low-lat: double neutron stars and others exotic objects

Credit: Cherry Ng
## HTRU: Setups

<table>
<thead>
<tr>
<th></th>
<th>Northern survey</th>
<th>Southern Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start date</strong></td>
<td>Summer 2010</td>
<td>Early 2008</td>
</tr>
<tr>
<td><strong>Telescope</strong></td>
<td>Effelsberg-100 m</td>
<td>Parkes-64 m</td>
</tr>
<tr>
<td><strong>Sky coverage</strong></td>
<td>$\delta &gt; -20^\circ$</td>
<td>$\delta &lt; +10^\circ$</td>
</tr>
<tr>
<td><strong>Integration time</strong></td>
<td>Low-lat: 1500 s</td>
<td>Low-lat: 4300 s</td>
</tr>
<tr>
<td></td>
<td>Mid-lat: 180 s</td>
<td>Mid-lat: 540 s</td>
</tr>
<tr>
<td></td>
<td>High-lat: 90 s</td>
<td>High-lat: 270 s</td>
</tr>
<tr>
<td><strong>Receiver</strong></td>
<td>7-beam 1.4-GHz receiver</td>
<td>13-beam 1.35-GHz receiver</td>
</tr>
<tr>
<td><strong>Backend</strong></td>
<td>Pulsar Fast Fourier Transform Spectrometer (PFFTS)</td>
<td>Berkeley-Parkes-Swinburne Recorder (BPSR)</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>240 MHz</td>
<td>340 MHz</td>
</tr>
<tr>
<td><strong>No. of channels</strong></td>
<td>512</td>
<td>1024</td>
</tr>
<tr>
<td><strong>Freq. resolution</strong></td>
<td>0.58 MHz</td>
<td>0.39 MHz</td>
</tr>
<tr>
<td><strong>Time resolution</strong></td>
<td>54 $\mu$s</td>
<td>64 $\mu$s</td>
</tr>
<tr>
<td><strong>No. of sky pointings</strong></td>
<td>~180 000</td>
<td>~43 000</td>
</tr>
<tr>
<td><strong>Data size</strong></td>
<td>~2.5 petabytes</td>
<td>~1 petabyte</td>
</tr>
</tbody>
</table>

*Credit: Cherry Ng, MPIfR, CSIRO*
Searching

Single-pulse search (pulsars, transients, FRBs)

Periodicity search (normal pulsars, MSPs)

Acceleration search (most exotic systems)

Tools

CPU

SIGPROC
(sigproc.sourceforge.net)

PRESTO
(http://www.cv.nrao.edu/~sransom/presto/)

GPU

HEIMDALL (Barsdell et al. 2012)

PEASOUP (E.Barr)
Status, discoveries

**HTRU-North**
Mid-lat: 38% observed, 37% processed*
Low-lat (3-min pointings): 68% observed, 65% processed*
19 new pulsars

**HTRU-South**
Mid-lat: 100% completed
Low-lat: 100% observed, 60% processed
High-lat: 100% observed, 42% processed
~190 new pulsars, 9 FRBs

* in the FAST PIPELINE (downsampled version of the data, without acceleration search)
A few HTRU highlights ...

“Diamond planet” pulsar (Bailes et al. 2011)


9 FRBs (Thornton et al. 2013, Champion et al. 2015)

60 new pulsars (Ng et al. 2015)
HTRU-North: most promising discoveries
PSR J1946+3417: a massive **eccentric** MSP with a low-mass helium white dwarf companion

**Formation mechanism**

1. Hierarchical triple system? *(Barr et al. 2013)*
2. Rotationally-delayed accretion induced collapse (RD-AIC)? *(Freire & Tauris 2014)*
3. Eccentricity growth through interaction with a circumbinary disk? *(Antoniadis 2014)*
4. A strange star scenario? *(Jiang et al. 2015)*
5. Something else... *(Barr, Freire, Berezina 2016, in prep.)*

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eccentricity</td>
<td>~0.134</td>
</tr>
<tr>
<td>Orbital period</td>
<td>~27 days</td>
</tr>
<tr>
<td>Companion mass</td>
<td>~0.27 solar</td>
</tr>
</tbody>
</table>
J1946+3417: Mass measurement

3 years of Effelsberg timing + Arecibo campaign

\[
f(m_p, m_c) = \frac{(m_c \sin i)^3}{(m_p + m_c)^2} = \frac{4\pi^2}{G} \frac{(a_p \sin i)^3}{P_b^2}
\]

\[
\omega = 3T_\odot^{2/3} \left( \frac{P_b}{2\pi} \right)^{-5/3} \frac{1}{1-e^2} \left( m_p + m_c \right)^{2/3}
\]

\[
\gamma = T_\odot^{2/3} \left( \frac{P_b}{2\pi} \right)^{1/3} c \frac{m_c (m_p + 2m_c)}{(m_p + m_c)^{1/3}}
\]

\[
r = T_\odot m_c
\]

\[
s = \sin i \quad T_\odot^{-1/3} \left( \frac{P_b}{2\pi} \right)^{-5/3} \frac{x (m_p + m_c)^{2/3}}{m_c}
\]

\[
\dot{P}_b = -\frac{192\pi}{5} T_\odot^{5/3} \left( \frac{P_b}{2\pi} \right)^{-5/3} f(c) \frac{m_p m_c}{(m_p + m_c)^{1/3}}
\]

\[
\Omega_{\text{good}} = \left( \frac{2\pi}{P_b} \right)^{5/3} T_\odot^{2/3} \frac{m_c (4m_p + 3m_c)}{2(m_p + m_c)^{1/3}} \frac{1}{1-e^2}
\]

\[
T_\odot = GM_\odot/c^3 = 4.9254909 \mu s
\]

(Damour & Deruelle 1982)

\[h_3(r, s) \text{ -- "Orthometric" amplitude of the Shapiro delay (Freire & Wex, 2010)}\]

\[
M1: 1.8840915 \pm 0.0277536
\]
Two **new bright recycled pulsars!!!**

PSR J2045+3633

Spin period: **31.68 ms**

PSR J2053+4650

Spin period: **12.58 ms**

Berezina et al. (2016, in prep)
PSR J2045+3633

Spin period: 31.68 ms
Orbital period: 32.3 days
Orbital eccentricity: 0.017
Min. companion mass: 0.86 solar

(usually eccentric orbit!)

“Mildly-recycled” system

Nature of the companion?
(Massive CO or ONeMg WD, probably)

Effelsberg, Jodrell Bank, Nançay, Arecibo

Shapiro delay, Omega dot?

Pulsar mass: 1.67 (+/- 0.35) solar
Companion mass: 0.97 (+/- 0.11) solar
PSR J2053+4650

Spin period: 12.58 ms
Orbital period: 2.45 days
Circular orbit!
Inclination angle: \( \sim 84^\circ \)

Min. companion mass: 0.81 solar mass
Nature of the companion?
(Massive CO or ONeMg WD, probably)
PSR J2053+4650: Mass measurement

Shapiro delay detected!

Pulsar mass: 1.52 (+/- 0.25) solar
Companion mass: 0.89 (+/- 0.08) solar
Summary: Prospects for PSR J2045+3633 and PSR J2053+4650

- Future precise mass measurements
- Identification of the companions
- Evolutionary scenarios
- Release to IPTA, NanoGRAV
Thank you for attention!