The High Time Resolution Universe

An awesome new survey for pulsars and their friends.
History
History
• Why & What we are doing
• Progress to date
• Most exciting results
Why & What
Another Multibeam Survey?

The HI-Multibeam system is the most successful pulsar discovery machine of all time.

PMPS finished, what should we do next?

e.g. Manchester et al. (2001) & many other publications!
Limits of analogue technology...

- The venerable “Analogue Filterbank”
- 13 beams, 96 channels per beam.
- Several racks worth of analogue electronics.

Parkes control room circa 1930
The awesome power of the digital age!

- Replace with 13 iBob digital signal processors + APSR computer cluster
- \(8x\) frequency resolution
- More bits, faster sampling rate...

Berkley-Parkes-Swinburne Recorder

Keith et al. (2011)
## Advantage of BPSR

<table>
<thead>
<tr>
<th></th>
<th>PMPS</th>
<th>HTRU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams per pointing</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>288 MHz</td>
<td>340 MHz</td>
</tr>
<tr>
<td>Channel Bandwidth</td>
<td>3 MHz</td>
<td>0.39 MHz</td>
</tr>
<tr>
<td>Sample Rate</td>
<td>250 us</td>
<td>64 us</td>
</tr>
<tr>
<td>Bits per sample</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Data Transfer Method</td>
<td>Tapes on a plane</td>
<td>High Speed Network + Tapes</td>
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Advantage of BPSR

Better frequency resolution reduces the dispersive effects of the ISM.

This vastly increases our survey volume and sensitivity for the fastest millisecond pulsars.

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In picture form...
Survey Design
## Survey Design

<table>
<thead>
<tr>
<th>Region</th>
<th>Low Latitude</th>
<th>Mid Latitude</th>
<th>High Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tobs</td>
<td>4300s</td>
<td>540s</td>
<td>270s</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.1 mJy</td>
<td>0.25 mJy</td>
<td>0.36 mJy</td>
</tr>
<tr>
<td>Npointings</td>
<td>1230</td>
<td>7312</td>
<td>36583</td>
</tr>
<tr>
<td>Data Volume</td>
<td>250 TB</td>
<td>190 TB</td>
<td>435 TB</td>
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- Region: b±3.5, b±15, δ < 10
- Data Volume: 250 TB, 190 TB, 435 TB
# Predicted Discoveries

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<tbody>
<tr>
<td>Pulsars</td>
<td>295</td>
<td>80</td>
<td>25</td>
<td>400</td>
</tr>
<tr>
<td>MSPs</td>
<td>33</td>
<td>28</td>
<td>14</td>
<td>75</td>
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</table>

Keith et al. (2010)
The HTRU Team

- CSIRO/ATNF (Aus)
  - Simon Johnston
  - Michael Keith
  - Sarah Burke*
- Swinburne (Aus)
  - Matthew Bailes
  - Willem van Straten
  - Andrew Jameson
  - Ramesh Bhat
  - Lina Levin
  - Paul Coster

- Jodrell Bank (UK)
  - Ben Stappers
  - Sam Bates*
  - Dan Thornton

- INAF Cagliari (Italy)
  - Andrea Possenti
  - Marta Burgay
  - Sabrina Milia

- MPIfR (Germany)
  - Michael Kramer
  - Cherry Ng

HTRU related PhD Students; *=Now graduated
Project PIs
Progress so far...
Discoveries to date

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<tr>
<td><strong>Observed Fraction</strong></td>
<td>44%</td>
<td>100%</td>
<td>30%</td>
<td>49%*</td>
</tr>
<tr>
<td><strong>Analysed Fraction</strong></td>
<td>3%</td>
<td>70%</td>
<td>6%</td>
<td>20%*</td>
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<tr>
<td><strong>Pulsars</strong></td>
<td>8</td>
<td>91</td>
<td>4</td>
<td>103</td>
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<tr>
<td><strong>MSPs</strong></td>
<td>0</td>
<td>20</td>
<td>1</td>
<td>21</td>
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On track to meet expectations!
New Discoveries
New Discoveries

Heaps of high DM MSP discoveries!
Growing the population

MSPs

All pulsars

Growing the population
Growing the population

MSPs

All pulsars

Growing the population
RRATS & Transients

- RRATS are pulsars which emit only once in 10/100/1000(?) rotations.
- So far we have found 15 new RRATS + 20 yet to be confirmed.
- No other transients so far, but the analysis is in early stages.
Individual Pulsars of Interest
• Period = 4.3 seconds
• DM = 980 cm$^{-3}$pc
• SNR = 300
• hidden in plain sight?

 Surprise!
PSR J1017-7156

A good timer with an interesting pulse profile

- Potential timing array pulsar - already included in PPTA
- Circular poln changes sign with freq!
- Two overlapping orthogonal modes with different spectral indices?
- Highlights the need for wide band Rx to understand emission

Keith et al. (2011)
PSR J1017-7156

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Keith et al. (2011)
PSR J1502-6752
A Very Low Mass Binary Pulsar with an exceptionally long period

- PSR J1502-6752 fits into the class of “VLMBP” - Very low mass binary pulsars.
- Companion mass is around $0.01 \, M_\odot$

Keith et al. (2011)
PSR J1502-6752
A Very Low Mass Binary Pulsar with an exceptionally long period

• Spin period is 22ms! Much longer than any other VLMBP.

• Previously assumed that the low mass meant long accretion period and therefore short spin period.

• How is all the mass lost?

Keith et al. (2011)
We keep adding more questions and possibilities here...

Generally thought that more mass loss meant longer accretion phase and therefore shorter spin period.
PSR J1719-1438
Yet another MSP?

• Our first solitary MSP, discovered December 2009.

• Kind of boring?

(Ominous blank space...
PSR J1719-1438
A planet pulsar!? 

• EXCEPT - observations at JBO quickly identified a 2.2 hour binary period 

• Companion mass close to jupiter mass!

• Is this another fantastic pulsar-planet system?

Bailes et al. (2011)
PSR J1719-1438
Exotic planet?

- Pulsar is 1000 times more massive than “planet”.
- Orbit $\sim 500,000$ km

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PSR J1719-1438
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- BUT - gravitational imbalance means Roche Lobe is only ~28,000 km
- Therefore density is 23 g cm$^{-3}$

Bailes et al. (2011)
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- Orbit ~500,000 km
- BUT - gravitational imbalance means Roche Lobe is only ~28,000 km
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- Jupiter - 2 g cm$^{-3}$
- Not a “normal” planet!

Bailes et al. (2011)
Transformation of a Star to a Planet!

- Somehow, the original companion star has lost 99.9% of its mass!
- Perhaps end product of UC LMXBs?
- How close does the WD come to total annihilation?
- Amazingly fascinating stuff...

Pulsar formed
Pulsar spin up
X-rays
WD ripped apart?
Heart of C-dwarf remains...
Transformation of a Star to a Planet!

- Somehow, the original companion star has lost 99.9% of its mass!
- Perhaps end product of UC LMXBs?
- How close does the WD come to total annihilation?
- Amazingly fascinating stuff...

Last line of the paper: “The chemical composition, pressure, and dimensions of the companion ensure that it will be crystallized (i.e, **diamond**).
Scientists discover the diamond planet

It’s the big bling theory as astronomers discover a girl’s best friend in the universe

Deborah Smith
SCIENCE EDITOR

AS bling goes, it doesn’t get bigger.

Australian astronomers have discovered a planet they think is made of diamond.

The galactic gem could be as large as 60,000 kilometres across – five times the diameter of Earth.

It is orbiting a tiny, dead, spinning star, called a pulsar, about 4000 light years away in the Milky Way.

CSIRO astronomer Michael Keith said the diamond planet was likely to be very hot and glowing white.

“It would probably look very pretty,” he said.

An international team, led by Matthew Bailes of Swinburne University of Technology in Melbourne, found the exotic object using telescopes including the radio telescope at Parkes. They were searching for pulsars – the lighthouses of the universe – which emit beams of radio waves as they spin rapidly.

They discovered a pulsar which is only about 20 kilometres across and rotating extremely fast – 175 times every second.

Slight variations in its pulse alerted the astronomers to the presence of the companion planet, which orbits the pulsar every two hours and 10 minutes. Dr Keith said the planet appeared to have been a massive star that lost more than 99 per cent of its mass.

Its density made it likely it comprise mostly of carbon atoms, crushed together in a crystalline structure “very similar to diamond.”

He joked that it would be priceless: “I recently got engaged so I know how much diamonds cost.”

Team member Willem van Straten said they hoped the planet was glowing white, because that would make it easier to see light from it using a telescope. The team was searching for millisecond pulsars because they were like accurate “clocks” whose regularity could be used to detect the presence of gravitational waves – theoretical ripples in space thought to be generated by cosmic events such as two black holes colliding.

The “holy grail” would be to find a pulsar orbiting a black hole, to see if Einstein’s general theory of relativity still holds in an extremely strong gravity field, he said. “You could study space and time in the vicinity of the black hole with a lot of precision.”

Somewhat unromantically the pulsar, with its diamond companion, is named PSR J1719-1438.
Favourite Radio Quote:
“It would take Shane Warne 4000 years to get there, if he were traveling at the speed of light.”
Transformation of a Star into a Planet
The High Time Resolution Universe Survey for Pulsars and Fast Transients Team
An awesome new survey for pulsars and their friends.

- Most successful ever RX + new all-digital backend
- Great new MSPs for timing experiments (Gravitational waves, clocks, ISM)
- Exotic binaries (Diamond planet, ULMBPs)
- Gamma-ray MSPs - links to Fermi
- Magnetar, RRATS, intermittent PSRs, etc...
- 1 PB database for transient searches