The Hunt for New Pulsars with the Green Bank Telescope

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What we'll talk about...

- Two most recent large-area GBT pulsar surveys – the 350 MHz Drift Scan Survey and the Green Bank North Celestial Cap Survey
  - Primary science goals
  - Progress so far
  - Highlights
  - Future work
- A brief overview of some targeted pulsar searches
• Anne Archibald (McGill)
• Aaron Berndsen (UBC)
• Jason Boyles (WVU)
• Fernando Cardoso (WVU)
• Angus Cherry (UBC)
• Jason Hessels (ASTRON)
• Rick Jenet (UTB)
• David Kaplan (UWM)
• Vicky Kaspi (McGill)
• Chen Karako (McGill)
• Vlad Kondratiev (ASTRON)
• Duncan Lorimer (WVU)

• Joeri van Leeuwen (ASTRON)
• Erik Madsen (UBC)
• Maura McLaughlin (WVU)
• Christie McPhee (UBC)
• Chris Pankow (UWM)
• Tim Pennucci (UVA)
• Scott Ransom (NRAO)
• Mallory Roberts (Eureka)
• Xavier Siemens (UWM)
• Ingrid Stairs (UBC)
• Kevin Stovall (UTB)
• ARCC (UTB/UWM)
First, some motivation

- We keep finding **cool new pulsars** whenever we look, so keep looking!
  - High precision MSPs for PTAs
  - Gravitational laboratories (Kramer et al. 2006; Freire et al. 2012)
  - Massive pulsars (e.g. Demorest et al. 2010)
  - Radio magnetars (Camilo et al. 2006, 2007; Levin et al. 2010)
  - And many, many more...
- Different surveys can be complementary
The importance of the GBT

- Largest fully steerable telescope in the world
- Can see parts of the sky that Arecibo and Parkes can't
- Relatively little RFI
- Several excellent low-noise receivers
- State-of-the art pulsar back-end

Image credits: Wikipedia & NRAO
The GBT Drift Scan survey

- Primary science goal: find high precision MSPs and exotic pulsars (young pulsars, RRATs, etc)
- Completed between May and August 2007 during GBT track repair shutdown
- Access to $-7.7^\circ < \delta < 38.4^\circ$ and $-20.7^\circ < \delta < 38.4^\circ$
The GBT Drift Scan survey

- Centered at 350 MHz with 50 MHz bandwidth
  - Most data recorded with 2048 channels
- Data analyzed in 140-s sections with 50% overlap
- 10347 sq deg, totaling 1491 hrs of observing time and 134 TB
  - 2800 sq deg reserved for Pulsar Search Collaboratory (Rosen et al. 2010)
- Data analysis now complete: 31 new pulsars including 7 MSPs ($P < 10$ ms)
The GBT Drift Scan survey
GBT Drift Scan Highlights

- J0348+0432 is a 39-ms recycled pulsars in a 2.4-hr orbit (Lynch et al. in prep)
  - Spectroscopic follow-up of the companion reveals a 0.17 Msun white dwarf (Antoniadis et al. in prep)
- Predicted to be a strong emitter of dipolar GWs by scalar-tensor theories of gravity
- Ongoing Arecibo timing will provide one of the most stringent tests ever of these alternative gravity theories (Antoniadis et al.)
J0348+0432 Pb-dot prediction

Courtesy of N. Wex
GBT Drift Scan Highlights

- J0337+1715 is a 2.7-ms MSP in a hierarchical triple (Ransom et al. in prep)
  - Inner companion is a WD on 1.6 day orbit
  - Outer companion on a 327 day orbit
- Already is proving to be a fantastic test-bed for 3-body dynamical theory

Courtesy of S. Ransom
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Courtesy of S. Ransom
GBT Drift Scan Highlights

- J2222-0137 (Boyles et al. in prep) is a 33-ms recycled pulsar with a > 1.1 Msun companion
  - Look for Shapiro delay measurement results soon
- J1923+2515 and J0931+1906 are 2 MSPs already included in NANOGrav and IPTA timing
- J1023+0038 (Archibald et al. 2009): The “missing link” pulsar
- 34 RRAT candidates discovered by Chen Karako (see tomorrow's talk)
The GBNCC survey

- Science goals similar to Drift Scan, but with particular emphasis on high declinations
  - More wide-separation baselines for pulsar timing arrays
  - Probe pulsar and RRAT populations in less well studied part of the Galaxy
- Data taking began in 2009 and is ongoing
  - Stage I covered $\delta > 38^\circ$ and is now complete
  - Stage II pushing south and will cover entire sky visible from the GBT
The GBNCC survey

- Centered at 350 MHz using newer GUPPI back-end
  - 100 MHz bandwidth with 4096 channels
  - 120-s pointed integrations
- Will use 2030 hrs and amass ~360 TB when completed
  - Early processing by Kevin Stovall at UTB
  - Most processing now at McGill using 2048 cores on the Guillimin supercomputer
- Preliminary results: 50 new pulsars including 9 MSPs
The GBNCC survey
J0636+51  
$P = 2.86$ ms  
DM = 11.1 pc/cc

J0645+51  
$P = 8.85$ ms  
DM = 18.2 pc/cc

J0741+66  
$P = 2.88$ ms  
DM = 15 pc/cc

J1122+78  
$P = 4.2$ ms  
DM = 11.2 pc/cc

J1710+49  
$P = 3.2$ ms  
DM = 7.1 pc/cc

J1649+80  
$P = 2.0$ ms  
DM = 31 pc/cc

Included in NANOGrav & IPTA
GBNCC Highlights

- J1816+4510 is a binary MSP in an 8.7-hr orbit around a > 0.16 Msun companion (Kaplan et al. 2012)
- Detected with Fermi and has UV/optical counterpart
GBNCC Highlights

- **J0510+38** is a 76-ms pulsars with $b=1^\circ$ (possible young pulsar?)
- **J0737+69** is a 6.8-s pulsar
  - Only 6 radio pulsars with longer periods (3 are RRATs)
- **J0636+51** is a 2.9-ms MSP in a 1.5 hr orbit
  - Lower limit on companion's density is 2x diamond planet (Bailes et al. 2012)
GBNCC Highlights

- 4 intermediate-period pulsars with $|b| > 10^\circ$ (possible relativistic binaries?)
- Several pulsars and MSPs with DM-distances $< 1$ kpc → promising targets for multi-wavelength follow-up
Targeted surveys: Globular Clusters

- The GBT has been amazing for finding GC pulsars
- The most promising GCs have been deeply searched as part of several projects (Ransom et al. 2005; Freire et al. 2008; Lynch et al. 2011a/b, 2012, Stairs et al. In prep)
- These included the fastest rotator (Hessels et al. 2006), potentially super-massive pulsars (Freire et al. 2008), and a potential double neutron star system (Lynch et al. 2012)
Targeted Surveys: Globular Clusters

144 pulsars in 28 clusters

Telescope PSRs
Jodrell Bank 5
Parkes 40
Arecibo 27
GBT 71
GMRT 1

Courtesy of S. Ransom
Targeted surveys: Fermi sources

- Fermi has revolutionized the search for field MSPs
  - 45 MSPs have been discovered by targeting bright, unidentified Fermi sources (see Ray et al. 2012)
  - 26 of these have been discovered using the GBT
Summary and Conclusions

- There are still lots of really cool pulsars to discover!
  - Pulsar-BH binary, planet systems, bridges between magnetars and pulsars, RRATs, massive pulsars...

- The GBT is one of the best instruments in the world for finding new pulsars

- The most recent GBT surveys have combined to discover 81 new pulsars (12 MSPs)

- The ongoing GBNCC survey promises to keep increasing this number by a lot (so stay tuned)