Highlights of Recent Radio Pulsar Observations at Arecibo

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Neutron Stars at the Crossroads of Fundamental Physics
Vancouver, 13 August 2005
1. The mass of PSR J0751+1807, a recycled pulsar in a binary with a Helium white dwarf

2. The Proper motion of the Hulse-Taylor double neutron star binary, B1913+16

3. The PALFA survey (Pulsar - Arecibo L-band feed Array)
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Collaborators: Ingrid Stairs, Eric Splaver, Oliver Löhmer, Axel Jessner, Michael Kramer, Jim Cordes
Mapping a Binary Orbit

pulsar

companion star
**Precession**

\[ \dot{\omega} = 3 \frac{G^{2/3}}{c^2} \left( \frac{P_b}{2\pi} \right)^{-5/3} \frac{1}{1-e^2} \left[ (m_1 + m_2) \right]^{2/3} \]

**Shapiro Delay**

\[ \Delta t = 2 \frac{G}{c^3} m_2 \ln \left[ 1 - \sin i \sin (\varphi - \varphi_0) \right] \]

**Grav Redshift/Time Dilation**

\[ \gamma = \frac{G^{2/3}}{c^2} \left( \frac{P_b}{2\pi} \right)^{1/3} e \frac{m_2 (m_1 + 2m_2)}{(m_1 + m_2)^{4/3}} \]

**Gravitational Radiation**

\[ \dot{P}_b = - \left( \frac{192\pi}{5} \right) \frac{G^{5/3}}{c^5} \left( \frac{P_b}{2\pi} \right)^{-5/3} \left( 1 + \frac{73}{24} e^2 + \frac{37}{96} e^4 \right) \frac{1}{(1-e^2)^{7/2}} \frac{m_1 m_2}{(m_1 + m_2)^{4/3}} \]
In neutron star-neutron star binaries, all pulsars and companions fall in a narrow range of masses, 1.18-1.44 $M_\odot$. 

<table>
<thead>
<tr>
<th>Pulsar</th>
<th>Pulsar Mass ($M_\odot$)</th>
<th>Companion Mass ($M_\odot$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSR B1913+16</td>
<td>1.4408±0.0003</td>
<td>1.3873±0.0003</td>
</tr>
<tr>
<td>PSR B2127+11C</td>
<td>1.349 ±0.040</td>
<td>1.363 ±0.040</td>
</tr>
<tr>
<td>PSR B1534+12</td>
<td>1.3332±0.0010</td>
<td>1.3452±0.0010</td>
</tr>
<tr>
<td>PSR J0737–3039</td>
<td>1.337 ±0.005</td>
<td>1.250 ±0.005</td>
</tr>
<tr>
<td>PSR J1756–2251</td>
<td>1.40 ±0.03</td>
<td>1.18 ±0.03</td>
</tr>
<tr>
<td>PSR J1518+4904</td>
<td>$\frac{PSR+Companion}{2}$ = 1.352±0.003</td>
<td></td>
</tr>
<tr>
<td>PSR J1811–1736</td>
<td>$\frac{PSR+Companion}{2}$ = 1.300±0.450</td>
<td></td>
</tr>
<tr>
<td>PSR J1829+2456</td>
<td>$\frac{PSR+Companion}{2}$ = 1.250±0.010</td>
<td></td>
</tr>
</tbody>
</table>
Where to look for heavier neutron stars?

Pulsar-White Dwarf binaries

Descendents of LMXBs

Accretion onto the NS:
• Increases pulsar mass
• Increases pulsar spin rate
• Decreases pulsar magnetic field
Pulsar + White Dwarf in 6.3 hour orbit
Very Circular, $e < 10^{-5}$
Discovered in 1993.
Intense ~annual campaigns since 1999.
Most recent data January 2004.

- Relativistic Orbit Decay Detected:
  \[ \frac{dP_b}{dt} = -(6.4 \pm 0.9) \times 10^{-14} \text{ s/s.} = -2.0 \pm 0.3 \mu\text{sec /year} \]
- First Measurement of Gravitational Radiation in a circular binary.
Timing fit is influenced by both orbit decay and Shapiro delay.

Orbit decay rate:

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Orbit decay rate:
\[ \dot{P}_b = -(6.4 \pm 0.9) \times 10^{-14} \]

Distribution for \( m_1 \) alone:
\[ m_1 = 2.1 \pm 0.2 \, M_\odot \]
What about biases from Galactic Acceleration and Proper Motion?

<table>
<thead>
<tr>
<th>Quantity</th>
<th>( \dot{P}_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Measurement</strong> ...</td>
<td>(-6.2 \times 10^{-14})</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>( \pm 0.8 \times 10^{-14})</td>
</tr>
<tr>
<td><strong>Acceleration biases</strong> ...</td>
<td></td>
</tr>
<tr>
<td>( z )-acceleration</td>
<td>(-0.1 \times 10^{-14})</td>
</tr>
<tr>
<td>Galactic rotation</td>
<td>( 0.1 \times 10^{-14})</td>
</tr>
<tr>
<td>Proper motion</td>
<td>( 0.2 \times 10^{-14})</td>
</tr>
<tr>
<td><strong>Intrinsic value</strong> ...</td>
<td></td>
</tr>
<tr>
<td>Measurement—Bias</td>
<td>(-6.4 \times 10^{-14})</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>( \pm 0.9 \times 10^{-14})</td>
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</table>

No Problem ... for now.
Any Evidence for an Interacting Binary?

Dispersion measure: there is **no** variability in dispersion measure at $\Delta DM < 4 \times 10^{-4}$ pc cm$^{-3}$.

Optical observations: Bassa, van Kerkwijk, & Kulkrani (in prep) see **no evidence of variability**. The secondary star is unusually cool and lacks a hydrogen atmosphere.

⇒ Interaction not an issue.
⇒ The orbit decay may safely be attributed to Gravitational radiation
An anti-correlation between pulsar mass and orbital period?

Masses of pulsars in Pulsar–Helium White Dwarf binaries measured by detection of relativistic phenomena in pulsar timing. (Exception: J1012+5307, mass is based on optical luminosity and spectroscopy of secondary.)

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Work in Progress....

Collaborators: Joel Weisberg, Joe Taylor
Stay Tuned....
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The collaboration...

...and more
What Next? Find More Pulsars!

- 7-Beam receiver at 1225-1525 MHz.
- Limited precursor observations began August 2004: 100 MHz bandwidth, 256 channels, 64 µs samples, 67 and 134 second integration times.
- New spectrometer in winter 2005-6: 300 MHz bandwidth, 1024 channels, 64 µs samples.
- Twelve pulsars discovered to date in low-resolution analysis.
- Several hundred new pulsars expected in full survey.

The first ALFA pulsar →
Single Pulse Searches

PSR J0628+09
J1906+0746
The first PALFA binary

Preliminary Parameters
(not ready for prime time -- please do not quote these results!)

- Period: 144 ms
- Age: 100 kyr
- Orbital Period: 3.98 hr
- Eccentricity: 0.085
- Periastron Advance: 7.5 deg/yr
- Total Mass: 2.59 Msun
- Distance: 5.5 kpc
Summary

1. The mass of PSR J0751+1807, a recycled pulsar in a binary with a Helium white dwarf
   It’s heavy: $2.1\pm0.2M_\odot$

2. The Proper motion of the Hulse-Taylor double neutron star binary, B1913+16
   It’s slow: 100-150 km/s

3. The PALFA survey
   (Pulsar - Arecibo L-band feed Array)
   It’s promising: 100s of new pulsars