Science with Radio Pulsar Astrometry

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- **Astrophysics**: Compare apparent $L_\gamma$ with absolute $\dot{E} = I\dot{\omega}\dot{\omega}$.  
  → Emission geometry, luminosity evolution.
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- **Gravitational physics**: Astrometric parameters for stable recycled pulsars independent of pulse timing. → Shklovskii effect corrections, break timing degeneracies.
- **Galactic electron density modeling**: improve DM-based distance estimates for entire population.
- **Other science**: velocity distributions, frame ties, NS cooling, etc.
The VLBA: An Astrometry Machine
Talk Outline

- **Applying VLB astrometry to pulsar timing:** Can we improve our sensitivity to gravitational waves?
- Astrophysics: NS mass for PSR J1023+0038.
- Astrometry for Fermi-detected pulsars.
- Previews of coming attractions.
Pulsar Timing Arrays and Gravitational Waves

- Time an array of exceptionally stable pulsars.
- Correlated timing residuals $\Rightarrow$ gravitational waves.
- NanoHz frequencies $\rightarrow$ multi-year timing campaigns.
Noise-induced errors in astrometry

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  - Red noise: post-fit residuals much lower.
- Effects are worse for redder noise.
- Effects worse for shorter data spans; reduced by denser sampling.
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- Reference frame mismatch between ICRF and DE405 etc: may require an ensemble coordinate offset.  
  ⇒ Conceptually easy, but changes fitting procedure.
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Astrophysics: NS mass for PSR J1023+0038.

Astrometry for Fermi-detected pulsars.

Previews of coming attractions.
PSR J1023+0038: an LMXB/MSP transition object

- Optical variability: accretion disk as recently as 2001.
- Radio pulsations: MSP (Archibald et al. 2009)

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- Optical variability: accretion disk as recently as 2001.
- Radio pulsations: MSP (Archibald et al. 2009)
  \[\Rightarrow\] Transition object from LMXB to recycled MSP.
- \(P = 1.69\) ms, Orbit = 4.75 hr.
- Variations in DM and \(P_{\text{orbit}}\).
- Frequency dependent eclipses.
- X-ray emission shows orbital modulation.
PSR J1023+0038: VLBA astrometry

VLBA obs, 2008–2010:

- $\mu_a = 4.76 \pm 0.03 \text{ mas/yr}$
- $\mu_d = -17.34 \pm 0.04 \text{ mas/yr}$
- $\pi = 0.73 \pm 0.02 \text{ mas}$

$\Rightarrow D = 1368^{+0.42}_{-0.39} \text{ pc}$

(Deller et al. 2012)
- Optical observations: companion $T \sim 5700$ K.
- Photometry: physical size of Roche lobe as function of $D$.

$$D = 2.20 \left( \frac{M_c}{M_\odot} \right)^{1/3} \text{kpc} \quad \text{(Thorstensen & Armstrong 2005).}$$
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\[ \Rightarrow \text{NS Mass} = 1.71 \pm 0.16 \text{M}_\odot. \]
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- Roche lobe not filled? If so, lower limit on mass.
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The Fermi gamma-ray space telescope

- LAT: Imaging high-energy gamma-ray telescope.
- 20 MeV—300 GeV; FoV covers 20% of the sky.
- Continuous scanning: whole sky imaged every 3 hours.
Fermi 3-month all-sky image

Note: Crab, Vela, Geminga, J1836+5925, and “Unidentified”…

Credit: NASA/DOE/Fermi LAT Collaboration
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... Many new pulsars, especially recycled ones!
Gamma ray luminosity vs Spindown $\dot{E}$

Suggestive? But distance uncertainty limits usefulness...
Case study: PSR J1614–2230

- Mass from Shapiro delay = 1.97(4) $M_\odot$ (Demorest et al. 2010).

$\Rightarrow$ Rules out most exotic quark matter equations of state.
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$\Rightarrow$ A precise distance may constrain the NS moment of inertia.
Ongoing astrometry programs

- **Fermi/VLBA**: A dozen $\gamma$-ray selected pulsars being followed. e.g., PSR J0751+1807: 4 epochs observed.
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- Can we do more? Yes we can!
  - **PSR$\pi$**: A large VLBA campaign on 280 pulsars!
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- Can we do more? Yes we can!
  - **PSRπ**: A large VLBA campaign on 280 pulsars!
    - 3–5 epochs observed (of 8) on 60 pulsars at 512 Mbps.
    - Preliminary parallaxes down to 10 μas for best 4.
    - At least 55 of 60 look promising...
    - Can expand sample once 2 Gbps bit rates available at VLBA.

https://safe.nrao.edu/vlba/psrpi/
PSRPi: a preview of coming attractions
PSRPi: more coming attractions
Is YOUR Neutron Star:

★ A radio emitter?
★ Brighter than ~1 mJy?
★ Closer than ~8 kpc?
★ North of -25 in Dec?

Measure a parallax* with the VLBA!

*Certain conditions, exclusions, and limitations apply. Please talk to the presenter or consult your friendly local expert about why the VLBA may be right for YOU!
A distance measuring service

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Collaborators and Acknowledgements

**VLBA astrometry collaboration:**

[https://safe.nrao.edu/vlba/psrpi/](https://safe.nrao.edu/vlba/psrpi/)

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Scott Ransom, Fernando Camilo, Paul Ray, Michael Kramer, Lucas Guillemot, Maura McLaughlin, David Smith, Agnes Fienga, Gilles Theureau, Roger Romani, David Thompson, et al.

**NANOGrav:** [http://nanograv.org/](http://nanograv.org/)