# VLBA Pulsar Parallaxes: Toward Microarcsecond Astrometry

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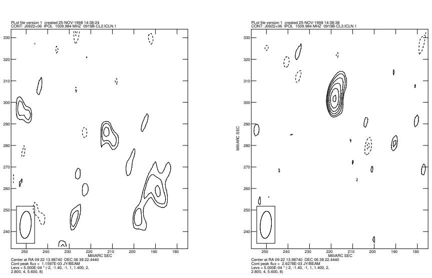
## The Basic Questions

- Origins: Identify supernova remnant associations and NS birth sites in stellar clusters; estimate true ages of both pulsars and associated supernova remnants from their angular separation and the proper motion.
- Evolution: Parallaxes and proper motions provide model-independent velocities, which allow accurate estimates of the population velocity distribution.
- Astrophysics: The highest velocities establish stringent constraints on supernova core collapse processes and the required birth kicks.
- Astrophysics: Accurate distances, combined with thermal emission spectra, constrain the size of the NS photosphere, with implications for NS atmospheres, cooling curves and the nuclear Equation of State.
- Environment: Parallax distances provide essential calibration for Galactic electron density models, and particularly for the local ISM.
- Verify solar system–extragalactic reference frame ties by comparing astrometry from pulse timing and VLBA astrometry.

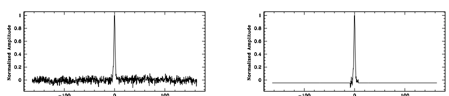
## The Techniques

- Phase referenced VLBI observations: Nod back and forth between a nearby calibrator and the target. Cycle times $\approx$ 90—120 seconds, over angular throws $\approx$ 2—5°.
- In-beam Calibration: Find and use weak source in same primary beam to correct phases $\Rightarrow$ minimal sky interpolation ($\sim 20'$) and no time interpolation required.

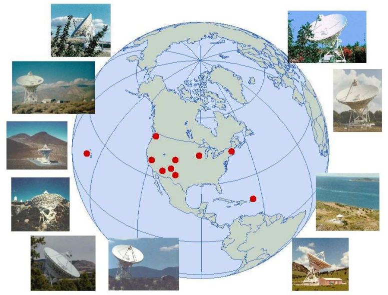


B0919+06 imaged with (left) phase referencing only and (right) in-beam calibration.

- Pulsar Gating: Use pulse timing solutions to gate correlator; boost S/N by $\sqrt{T_{on}/(T_{on}+T_{off})}$.




Ungated (left) and gated (right) pulse profiles.

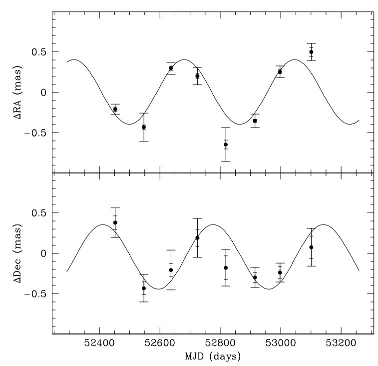


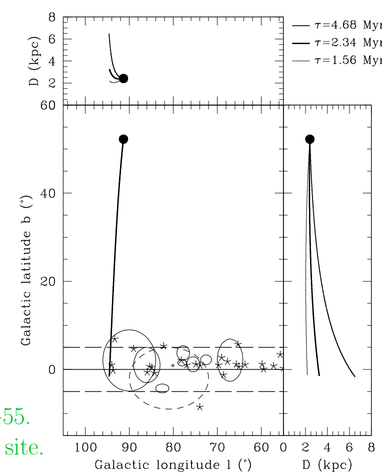
## The Project

- Large VLBA project now concluded: over 500 hours of observations.
- 26 pulsars observed for 8 epochs each, over a span of 2 years.
- At least 20 new parallaxes are expected, more than doubling the sample of known pulsar parallaxes.
- First results now published: Chatterjee *et al.* 2005, *ApJL*, 630, 1.

## Getting its Kicks: A VLBA Parallax for B1508+55

$\mu_\alpha = -73.61 \pm 0.04$ mas/yr, $\mu_\delta = -62.62 \pm 0.09$ mas/yr, $\pi = 0.415 \pm 0.037$ mas.




Above: The parallax signature of B1508+55.
Right: B1508+55 traced back to its birth site.

- Model-independent $D = 2.37^{+0.23}_{-0.20}$ kpc; $V_\perp = 1083^{+103}_{-90}$ km s$^{-1}$, the highest velocity directly measured for a neutron star.
- At its spindown age $\tau = 2.34$ MYr, birth at $|z| < 0.2$ kpc for modest (unknown) radial velocities of 0—300 km s$^{-1}$: $\Rightarrow$ self-consistent picture.
- Binary disruption alone is insufficient to impart the required birth velocity, and a natal kick is indicated. In 2-dimensional simulations, kicks $\sim$ 1000 km s$^{-1}$ have been produced. However, the first full 3-dimensional simulations of supernova core collapse have trouble producing high velocities.

$\Rightarrow$ Observations set the bar for simulations of supernova core collapse to clear.
$\Rightarrow$ Contributions from both binary disruption and a natal kick are possible.

## Separated at Birth: B2020+28 and B2021+51

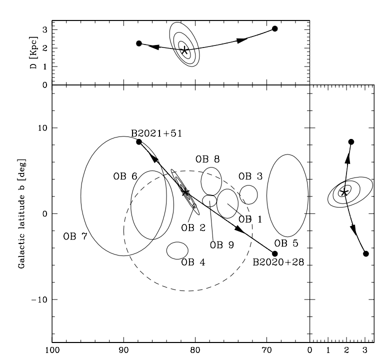
- VLBA astrometry for B2020+28, B2021+51 (Brisken *et al.* 2002, *ApJ*, 571, 906): model-independent distances and velocities.

B2020+28: $D = 2.7^{+1.3}_{-0.7}$ kpc; $\tau = 2.88$ MYr

B2021+51: $D = 2.0^{+0.3}_{-0.2}$ kpc; $\tau = 2.75$ MYr

- Trace orbits in Galactic potential: a common origin in/near the Cygnus Superbubble, at an age $\approx$ their spindown ages (Vlemmings, Cordes, & Chatterjee 2004, *ApJ*, 610, 402).
- Birth history: progenitors had comparable masses, and were in a binary which was disrupted by the second supernova explosion.

Below: Trajectories in the Galactic potential.

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