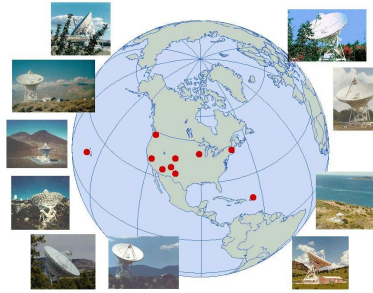


# VLBA Pulsar Parallaxes: Toward Microarcsecond Astrometry

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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.

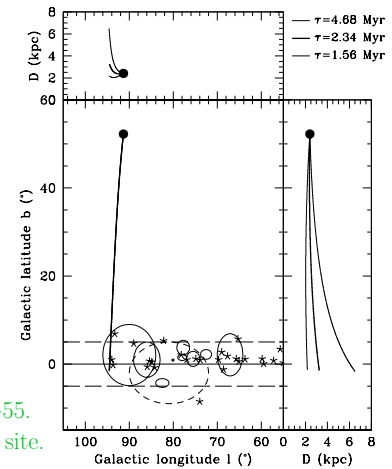
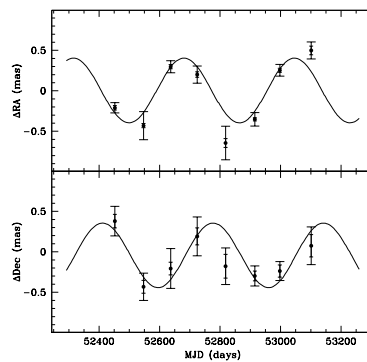


## The Project

- **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

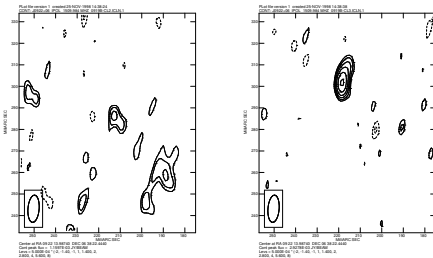
$$\mu_\alpha = -73.61 \pm 0.04 \text{ mas/yr}, \mu_\delta = -62.62 \pm 0.09 \text{ mas/yr}, \pi = 0.415 \pm 0.037 \text{ mas.}$$



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

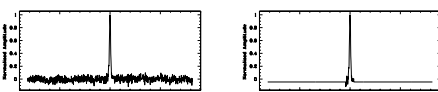
## The Techniques

- **Phase referenced VLBI observations:** Nod back and forth between a nearby calibrator and the target. Cycle times  $\approx 90$ – $120$  seconds, over angular throws  $\approx 2$ – $5^\circ$ .
- **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.

- 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.

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

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

- 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.

