Measuring Magnetar Velocities

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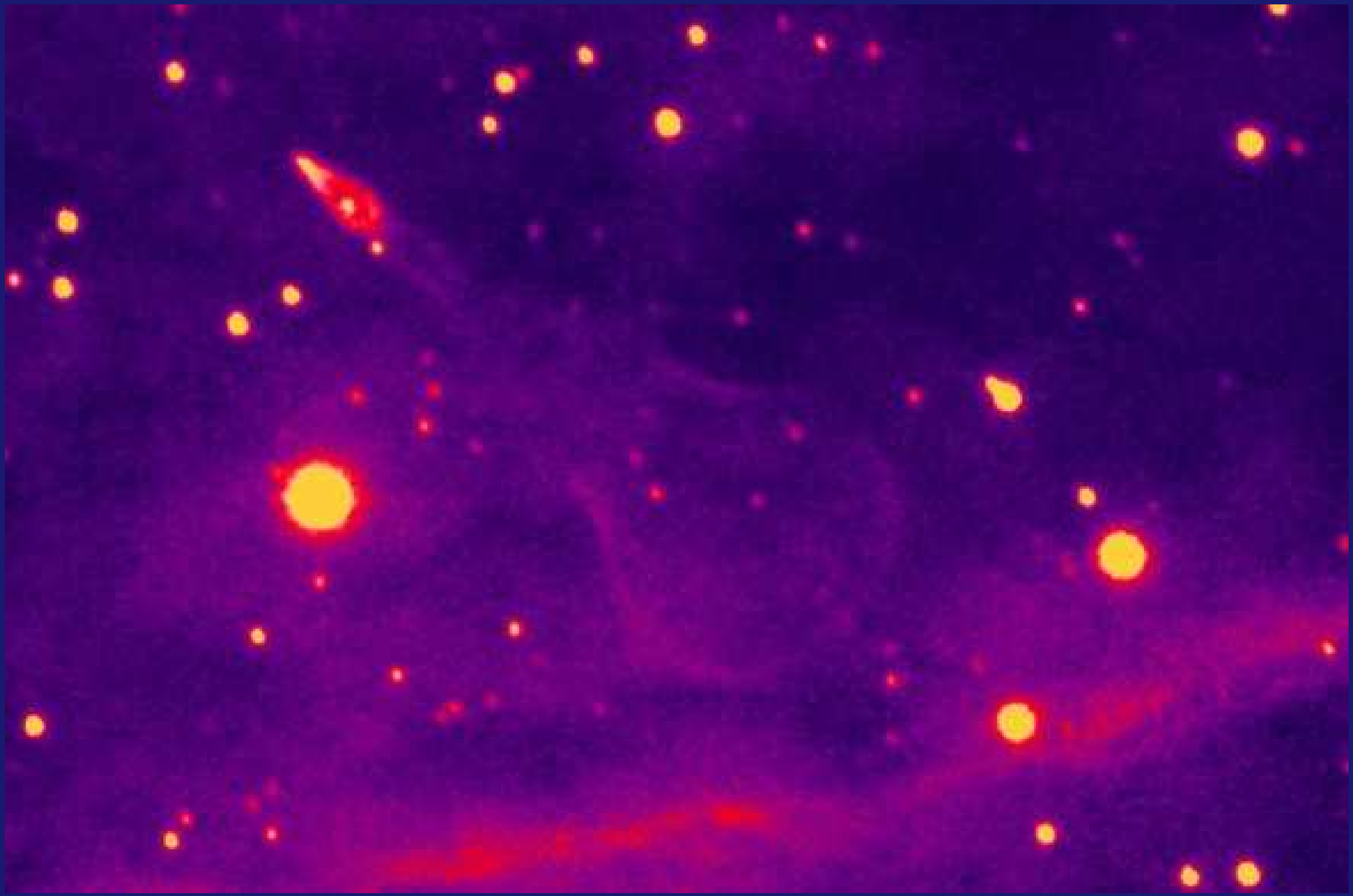
Neutron Stars are a high velocity population

Mean 3D birth velocity of young pulsars ~ 400 km s^{-1}.
Distribution has a high velocity tail $\gtrsim 1000$ km s^{-1}.



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Mean 3D birth velocity of young pulsars ~ 400 km s^{-1}.
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Origin of these high velocities?

- Binary disruption $\rightarrow$ Insufficient.
- Electromagnetic rocket effect $\rightarrow$ May play a role?
- Natal kicks from supernovae $\rightarrow$ Very plausible.

Core Collapse and Kicks

SN core collapse $\longrightarrow$? $\longrightarrow$ Birth kicks.

Core Collapse and Kicks

SN core collapse $\rightarrow$? $\rightarrow$ Birth kicks.

- Convective or hydrodynamic instabilities?

(e.g., SASI, acoustic modes, etc.)

- Driven by ultra-strong magnetic fields?

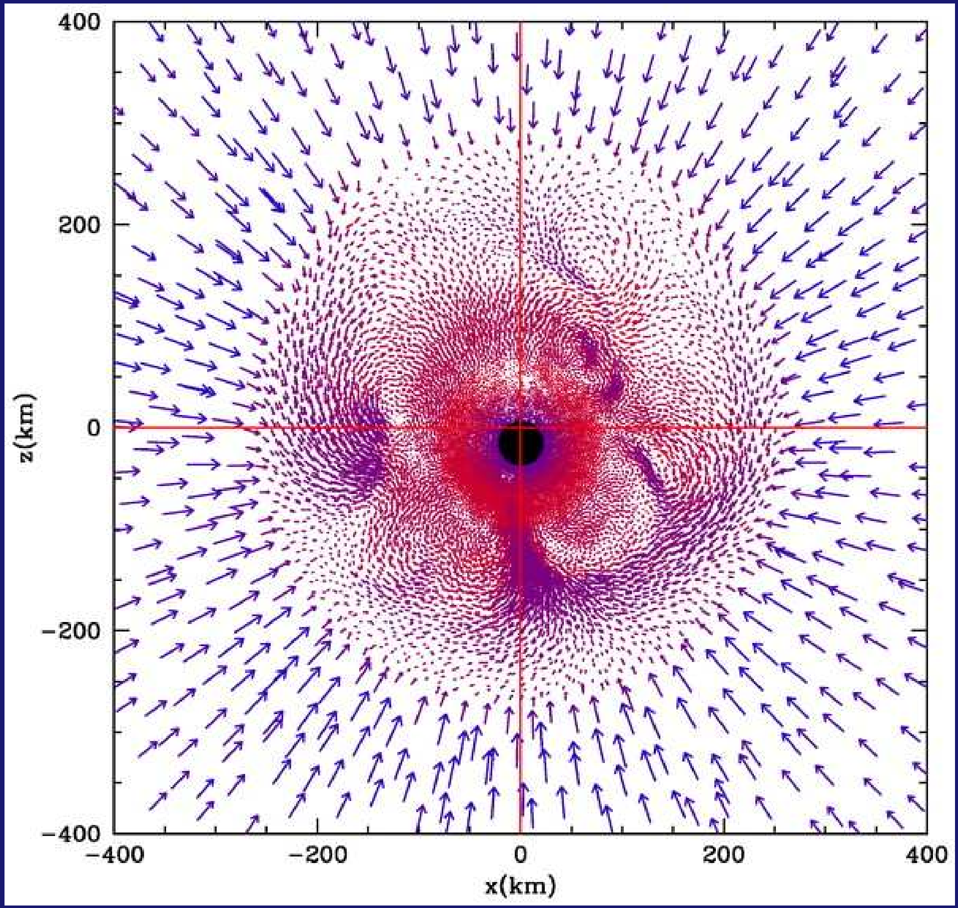
(e.g., Parity violation and asymmetric ν_e^- emission?)
(or, e.g., Magnetorotational instabilities?)

Core Collapse and Kicks

Hydrodynamic core collapse simulations $\rightarrow$ large kicks:

2D simulations find cases with $V > 1000$ km/s.
(e.g., Burrows & Hayes 1996; Muller & Janka 1997; Scheck et al. 2004)

Core Collapse and Kicks



But the first 3-dimensional simulations (Fryer 2004) have trouble producing kicks > 200 km s^{-1} due to fallback.

An Observational Test

- Hydrodynamic simulations show promise — e.g., recent simulations by Burrows et al., Janka et al., Fryer et al.

- Magnetic field-driven mechanisms, either with asymmetric neutrino emission, or with magnetorotational instabilities, may also work...

How do we discriminate between models?

An Observational Test

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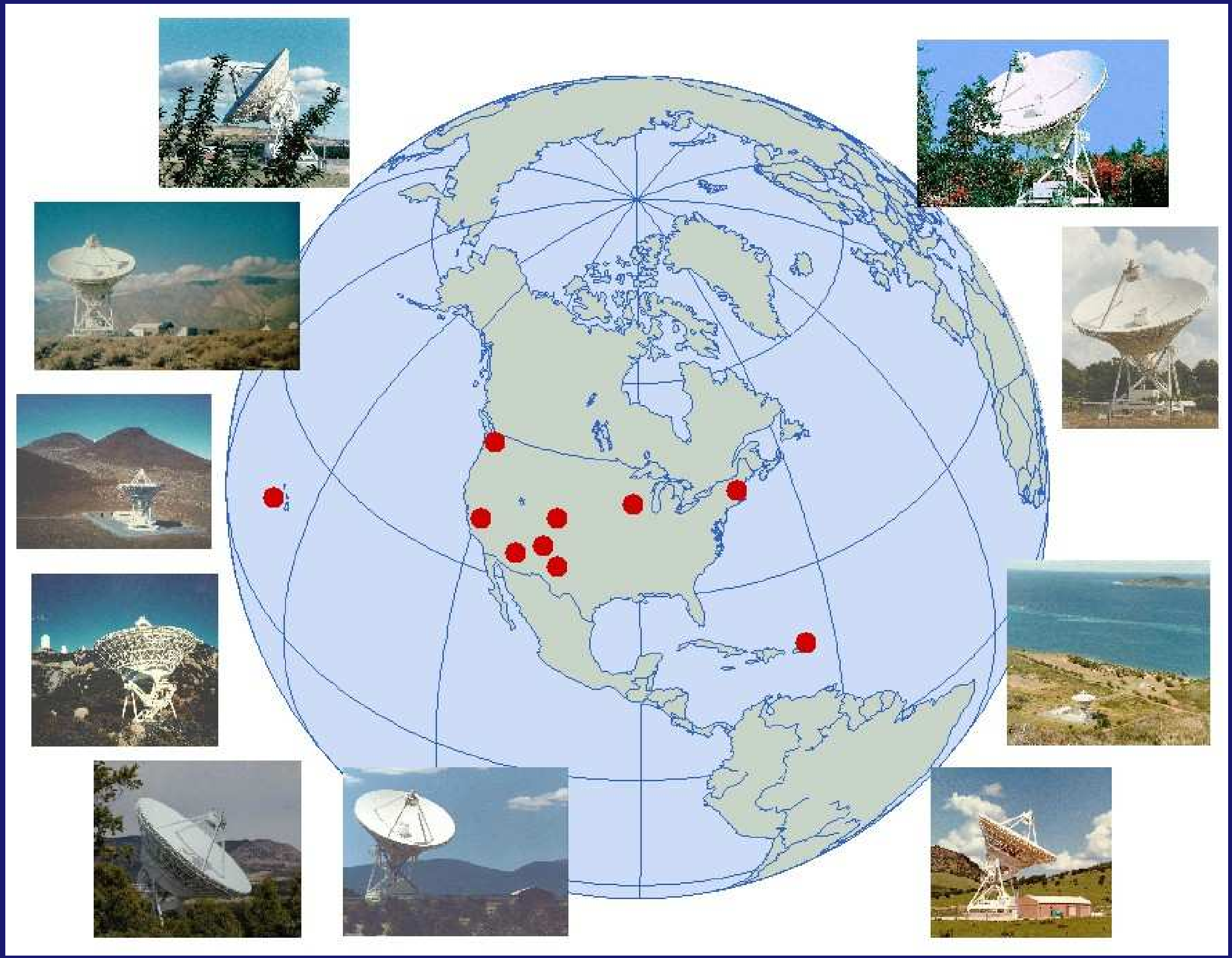
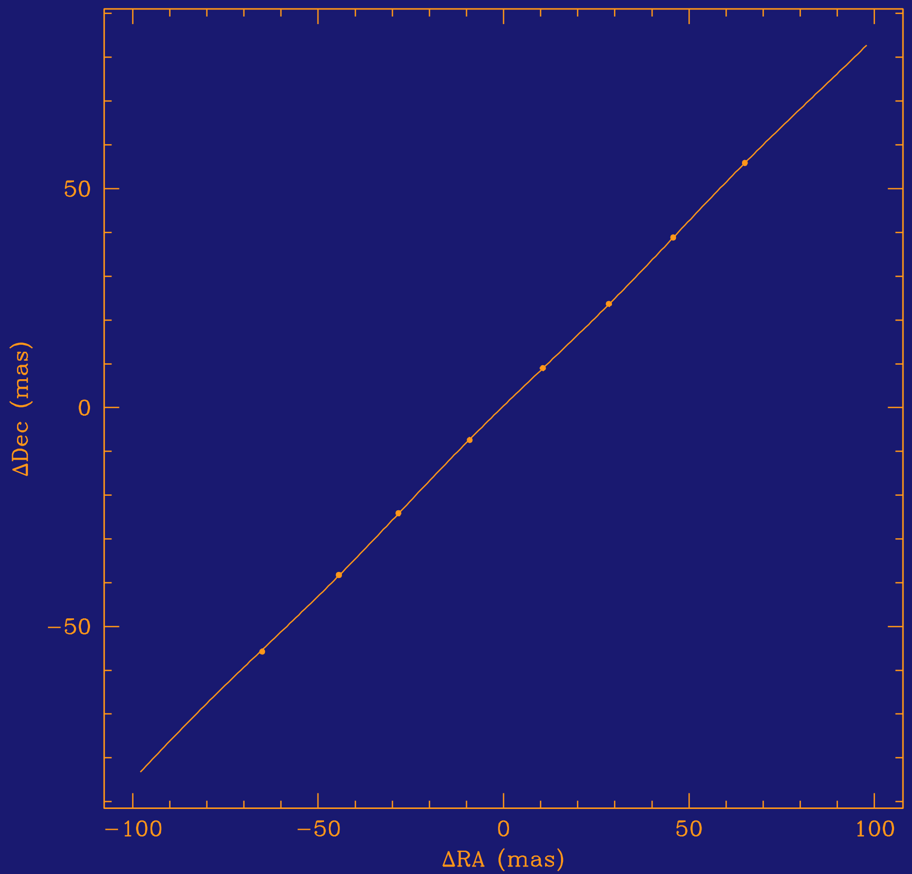
$\Rightarrow$ Nature provides a way to twiddle the settings on the dial: Compare velocities of magnetars and ordinary radio pulsars.

[e.g., Magnetar $V \gg 1000$ km/s? (Duncan & Thompson 1992)]

VLBA: Parallaxes and Proper Motions



Astrometric Results for PSR B1508+55



μ_a = -73.61 ± 0.04 mas yr^{-1}

μ_d = -62.62 ± 0.09 mas yr^{-1}

π = 0.42 ± 0.04 mas

(with Vlemmings, Brisken, Lazio, Cordes,
Goss, Thorsett, Fomalont, Lyne, Kramer)

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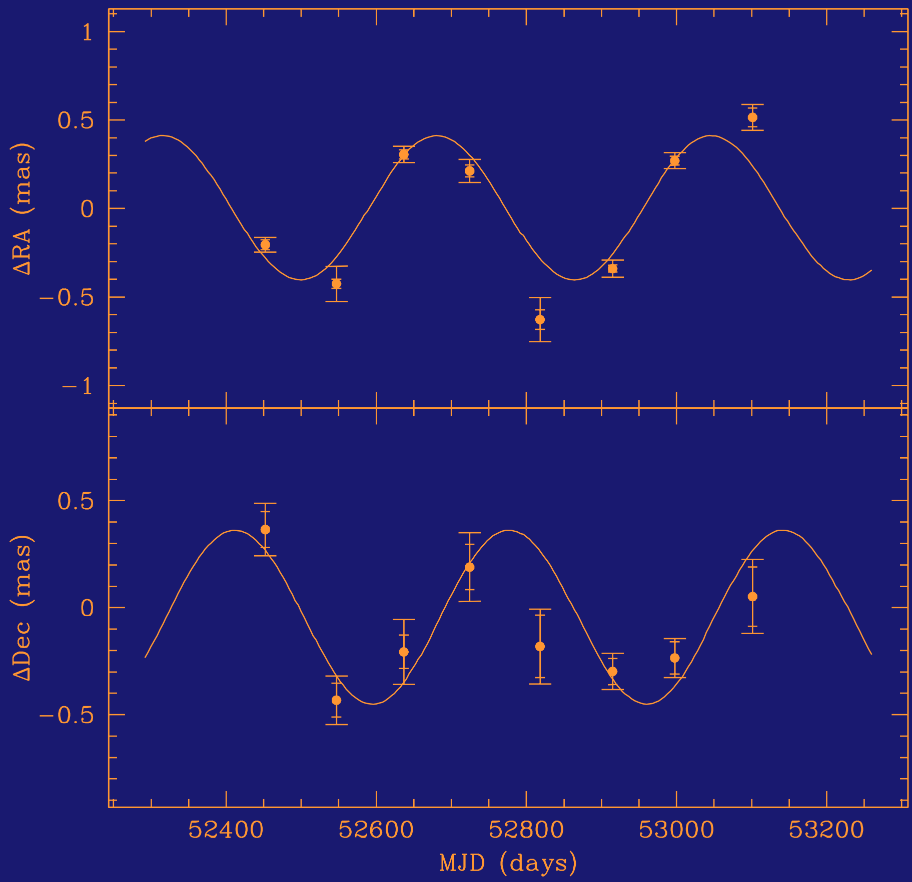

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π = 0.42 ± 0.04 mas

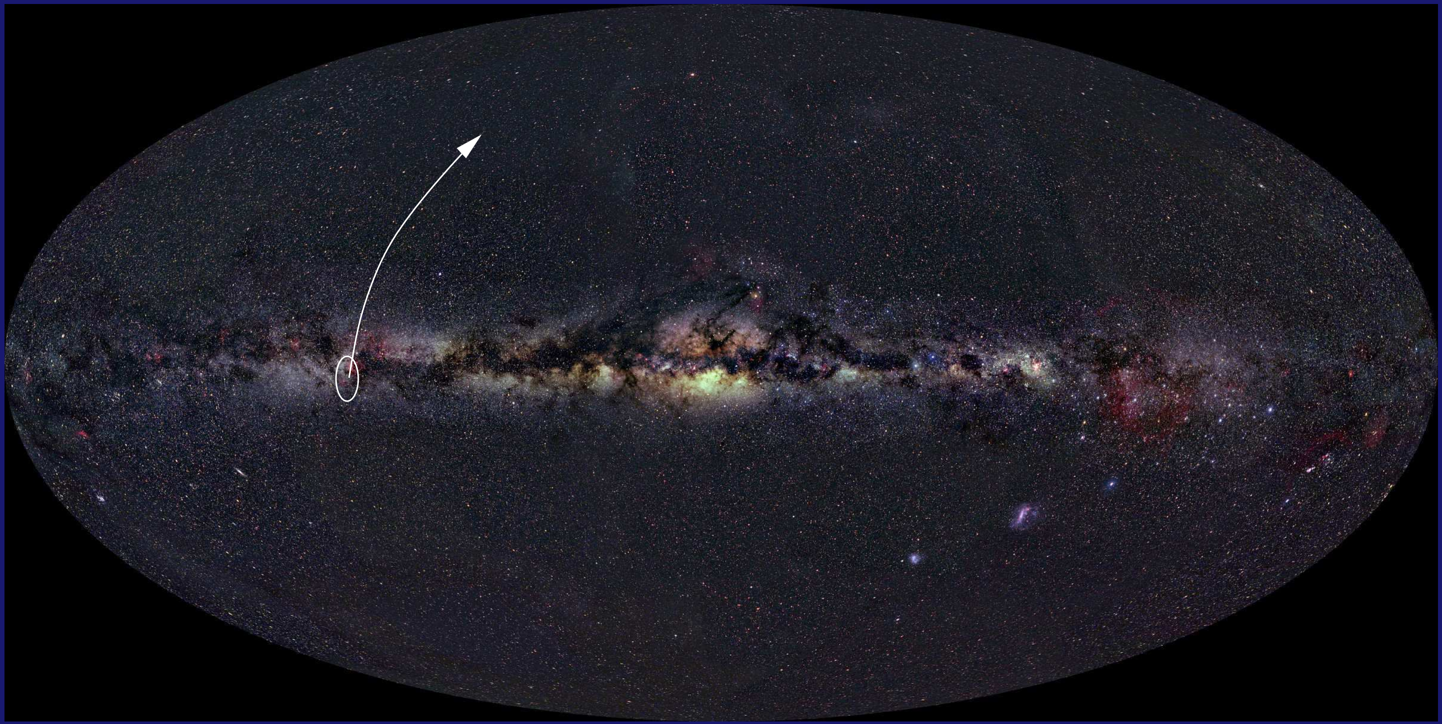
Distance = $2.37^{+0.23}_{-0.20}$ kpc

$V_\perp$ = 1083^{+103}_{-90} km s^{-1}

The highest measured model-independent velocity yet!

(Chatterjee et al. 2005)

The Birth Site of B1508+55



Orbit of B1508+55 overlaid on Axel Mellinger's image of the Galaxy.

- Current Galactic latitude = 52.3°.
- Trace back orbit in Galaxy: born in Galactic plane.
- Birth in or near Cygnus OB associations.

B1508+55: Getting its Kicks

- B1508+55: implied birth velocity ≈ 1100 km s^{-1}.
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(e.g., recent work by Janka et al., Fryer et al., Blondin et al., Burrows et al.)

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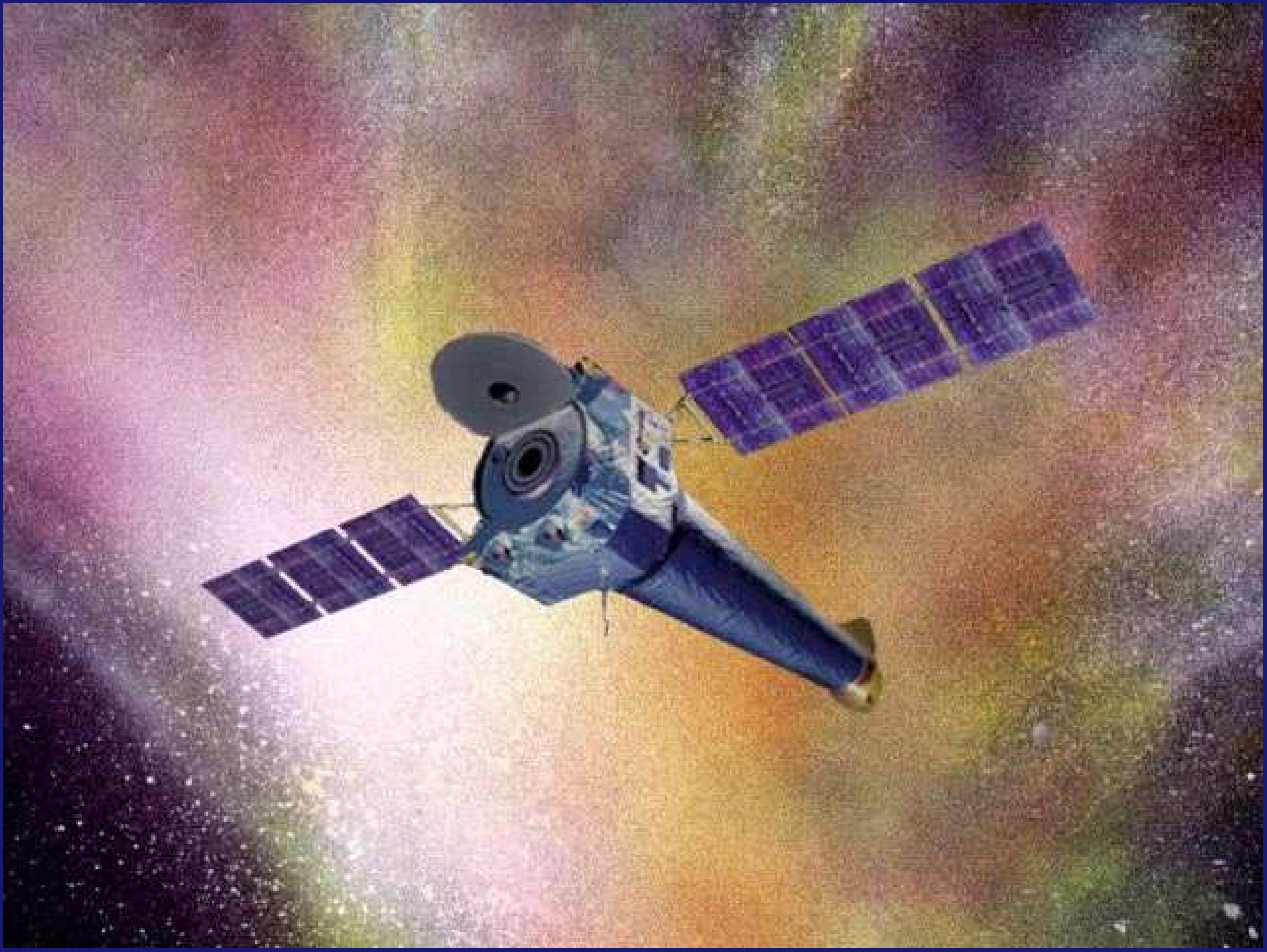
$\Rightarrow$ High velocities impose severe constraints on core collapse and kick velocity scenarios.

Astrometry with *Chandra*



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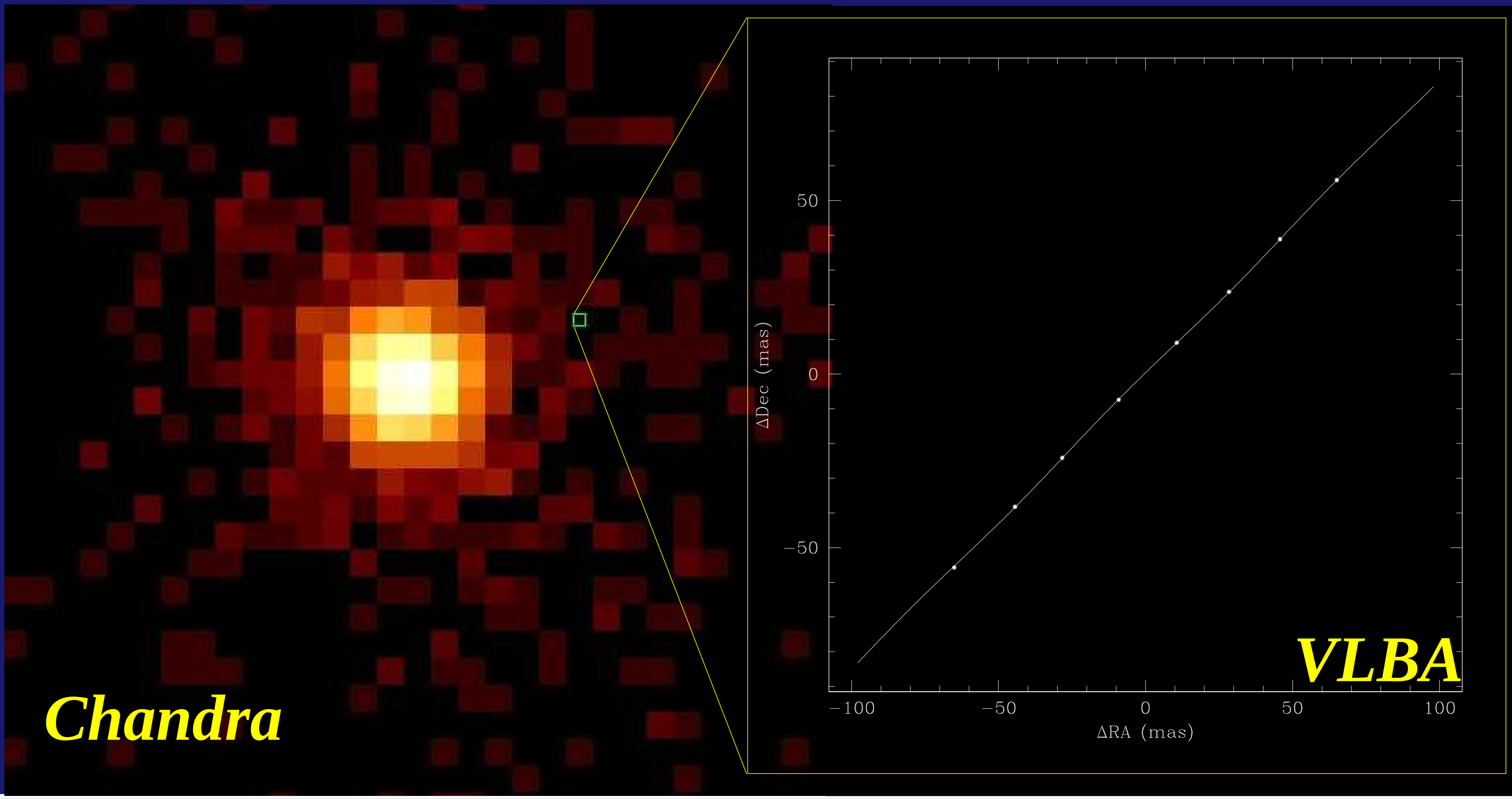


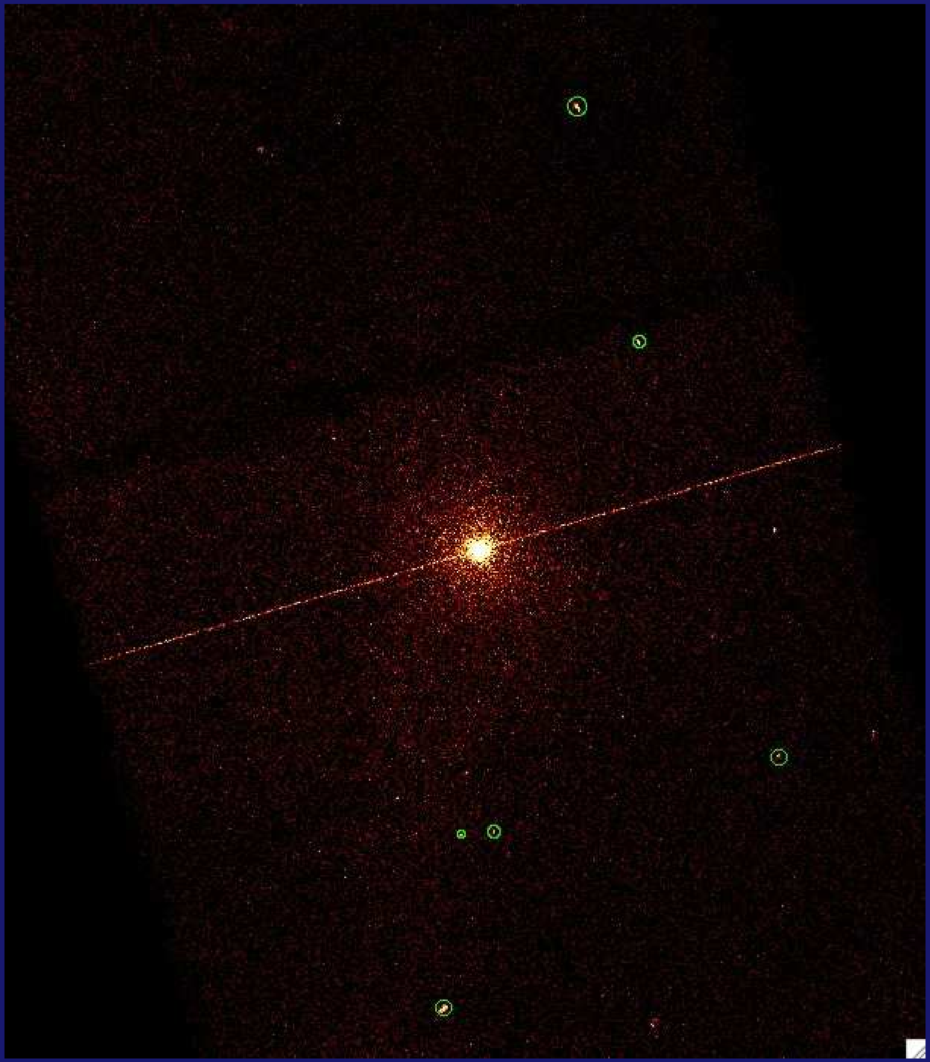
Astrometry with Chandra

- *Chandra* has the best resolution of any X-ray telescope, past, present, or on the drawing board.
- Even so, precision astrometry is hard!

$\Rightarrow$ Need observations separated by many years.

(With Kaplan, Gaensler, Slane; student Chris Hales)

AXP 1E 2259+586 with Chandra in 2000



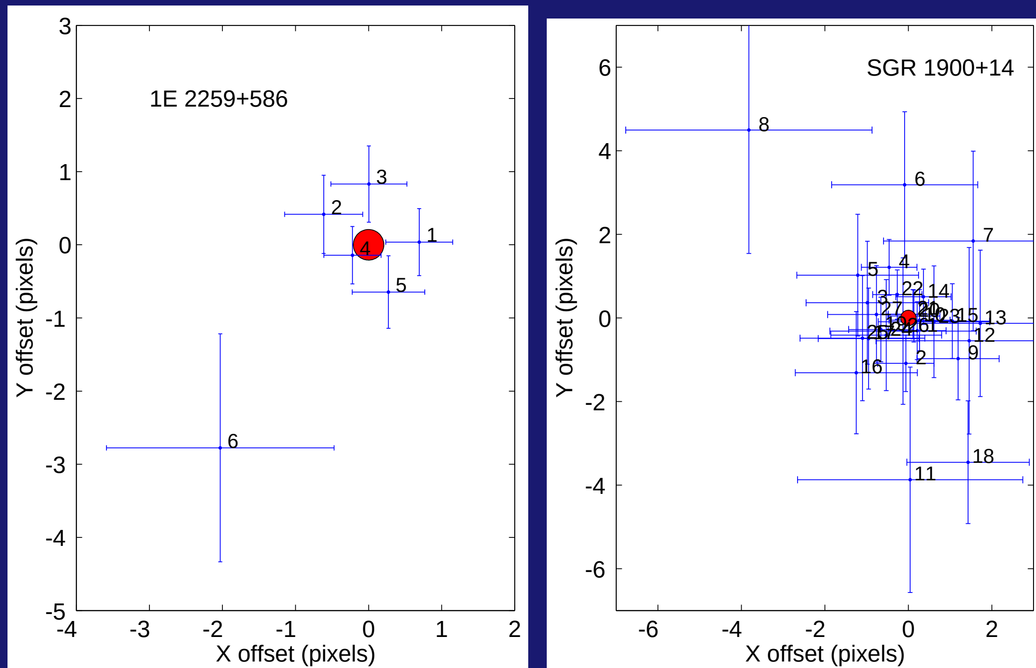
AXP 1E 2259+586 with Chandra in 2006

Astrometry with Chandra

- Construct reference frame with background sources.
- Extract magnetar position by cross-correlation with piled up PSF model.
- Verify astrometry against standard source extraction: lower precision, especially due to pile up.
- Verify astrometry using read-out streak.

(Kaplan, Chatterjee, Hales, Gaensler, Slane, 2008, AJ, in press)

Reference Frame

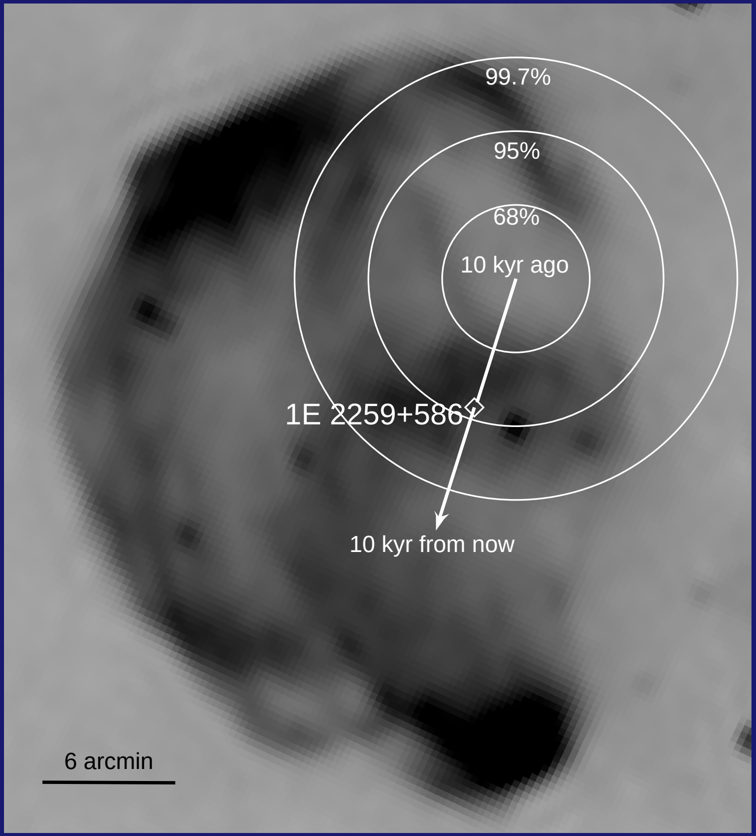


Reference frames matched to:

- ≈ 0.2 pixels for SGR 1900+14,
- ≈ 0.25 pixels for AXP 1E2259+586.

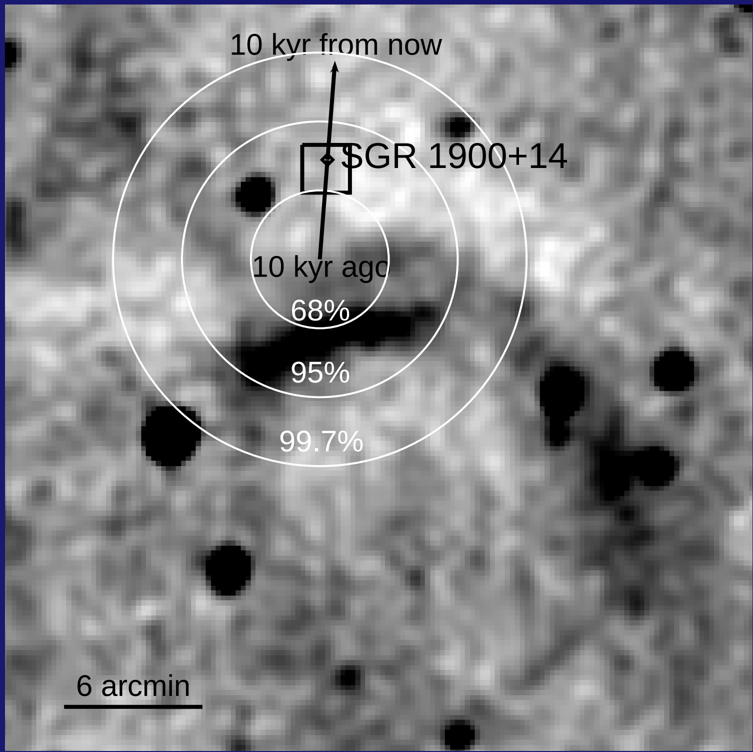
We have 2-epoch results:
will need at least 3 to get firm answers.

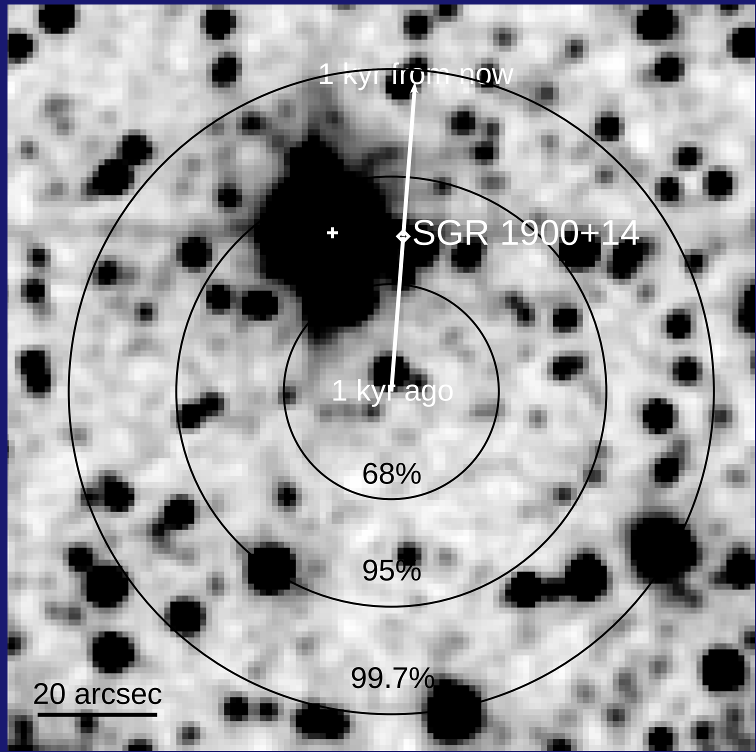
Astrometry Results: AXP 1E2259+586



- $\langle\mu\rangle = 42$ mas/yr; 90% upper limit is 65 mas/yr.
$\Rightarrow$ V$_{\perp,90} < 930\ d_3$ km/s.
- Asymmetric expansion of the remnant CTB 109?

Astrometry Results: SGR 1900+14

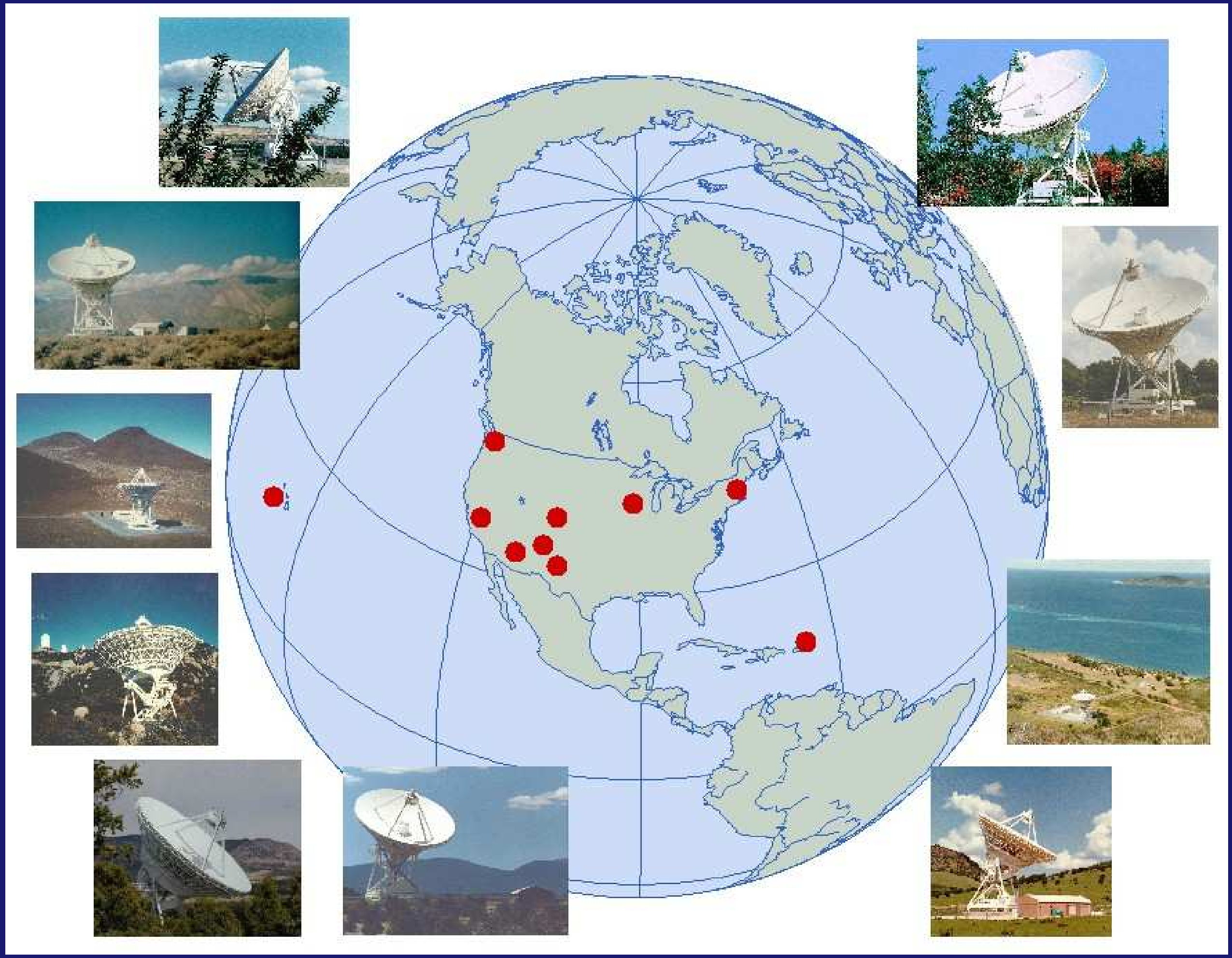




- $\langle\mu\rangle = 33$ mas/yr; 90% upper limit is 54 mas/yr.
$\Rightarrow$ V$_{\perp,90} < 1300\ d_5$ km/s.

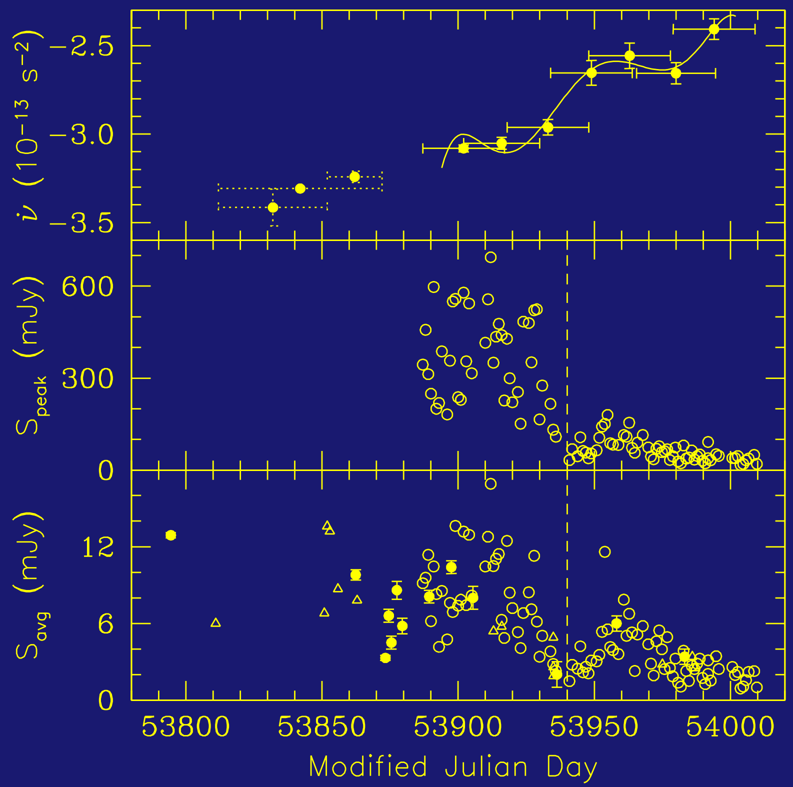
- An association with the SNR G42.8+0.6 may be viable? But birth in a nearby massive cluster is not ruled out.

Magnetar proper motion with the VLBA?



Magnetar XTE J1810–197

- Camilo et al. (2006): Transient pulsed radio emission!
- Rapidly fading...

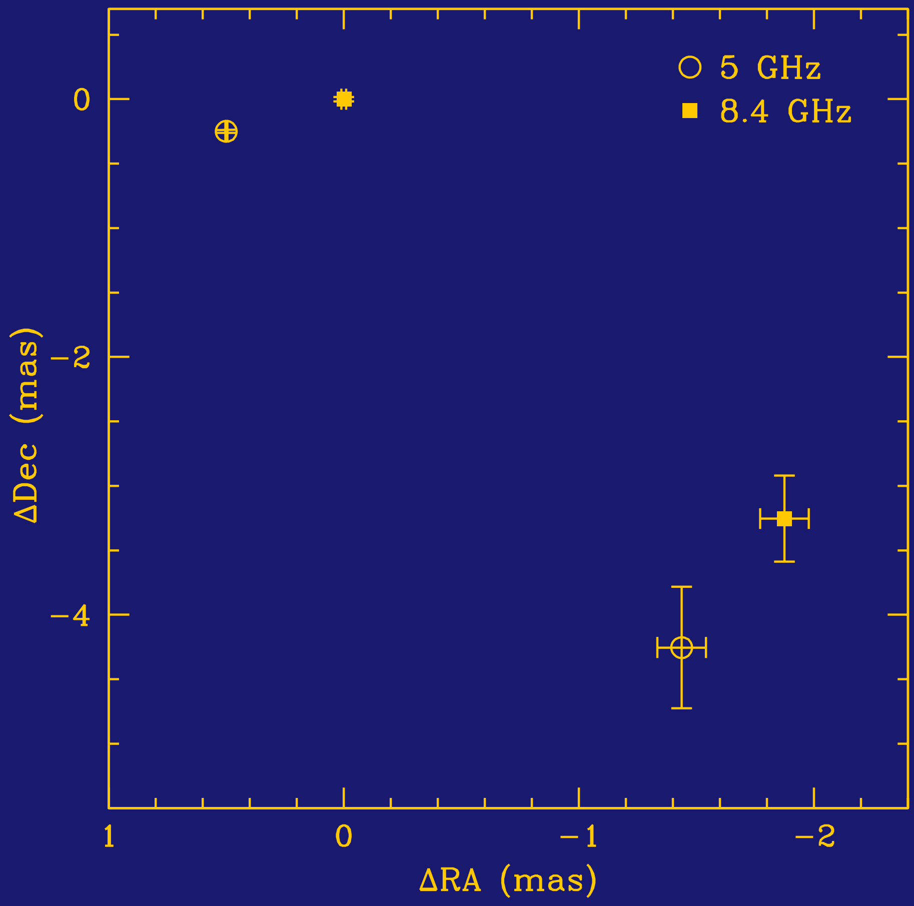


(from Camilo et al. 2006)

Magnetar XTE J1810–197

- Camilo et al. (2006): Transient pulsed radio emission!
- Rapidly fading...
- But bright enough for the VLBA at 5 GHz, 8.4 GHz.

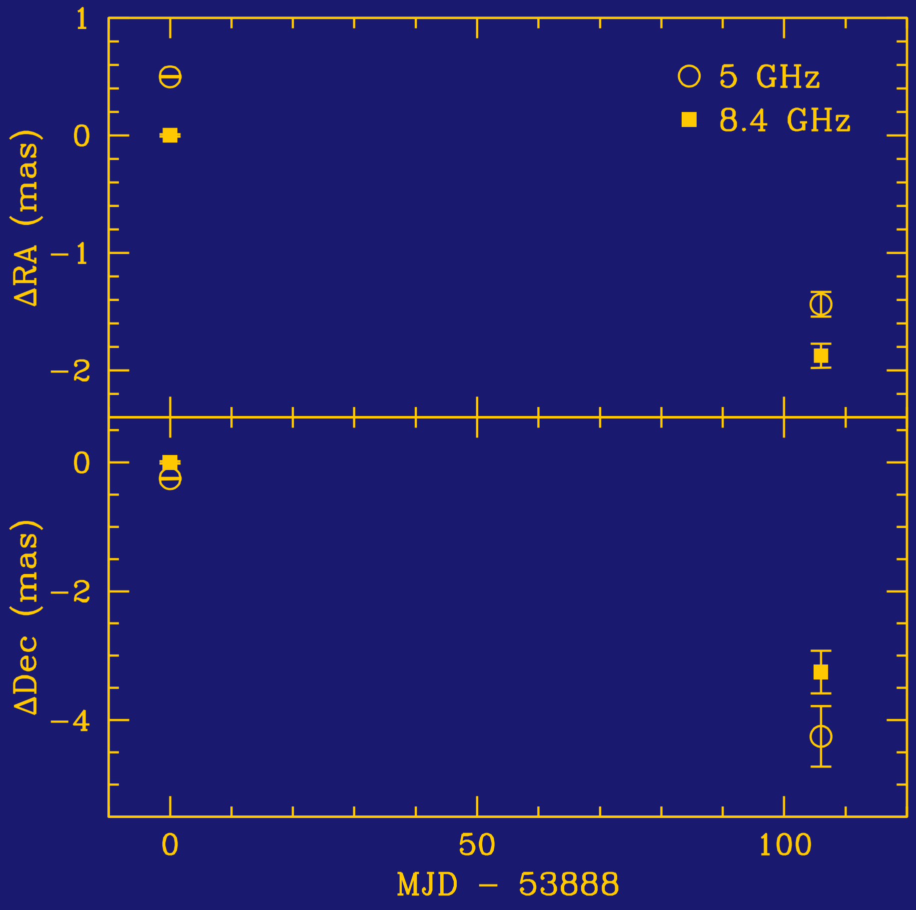
A Magnetar Proper Motion



μ_a = -6.60 ± 0.06 mas yr^{-1}

μ_d = -11.7 ± 1.0 mas yr^{-1}

A Magnetar Proper Motion



μ_a = -6.60 ± 0.06 mas yr^{-1}

μ_d = -11.7 ± 1.0 mas yr^{-1}

$\Rightarrow$

For $D = 3.5 \pm 0.5$ kpc,

V$_\perp \sim 220$ km s^{-1}

[$180 - 270$ km s^{-1}]

For this one object, no exotic kick mechanism is required.

(Helfand, Chatterjee, Brisken et al. 2007)

Concluding Thoughts

The energy dissipation, initial spins, surface magnetic fields, birth kick velocities and progenitor masses of NS are all interwoven with the physics of supernova core collapse.

With precise astrometry:

$\longrightarrow$ Determine distances, velocities, associations, ages.

$\longrightarrow$ PSR B1508+55 sets a high bar for natal kick models.

$\longrightarrow$ SGR 1900+14 may, in fact, be associated with a distant SNR? If so, high velocity. Or birth in nearby massive cluster.

$\longrightarrow$ Upper limits on velocity of magnetars.

$\longrightarrow$ Magnetar XTE J1810$-$197 does not require exotic kicks.

$\Rightarrow$ We can tease apart the various threads of the interdependence.