Science with Radio Pulsar Astrometry

Shami Chatterjee

Cornell University

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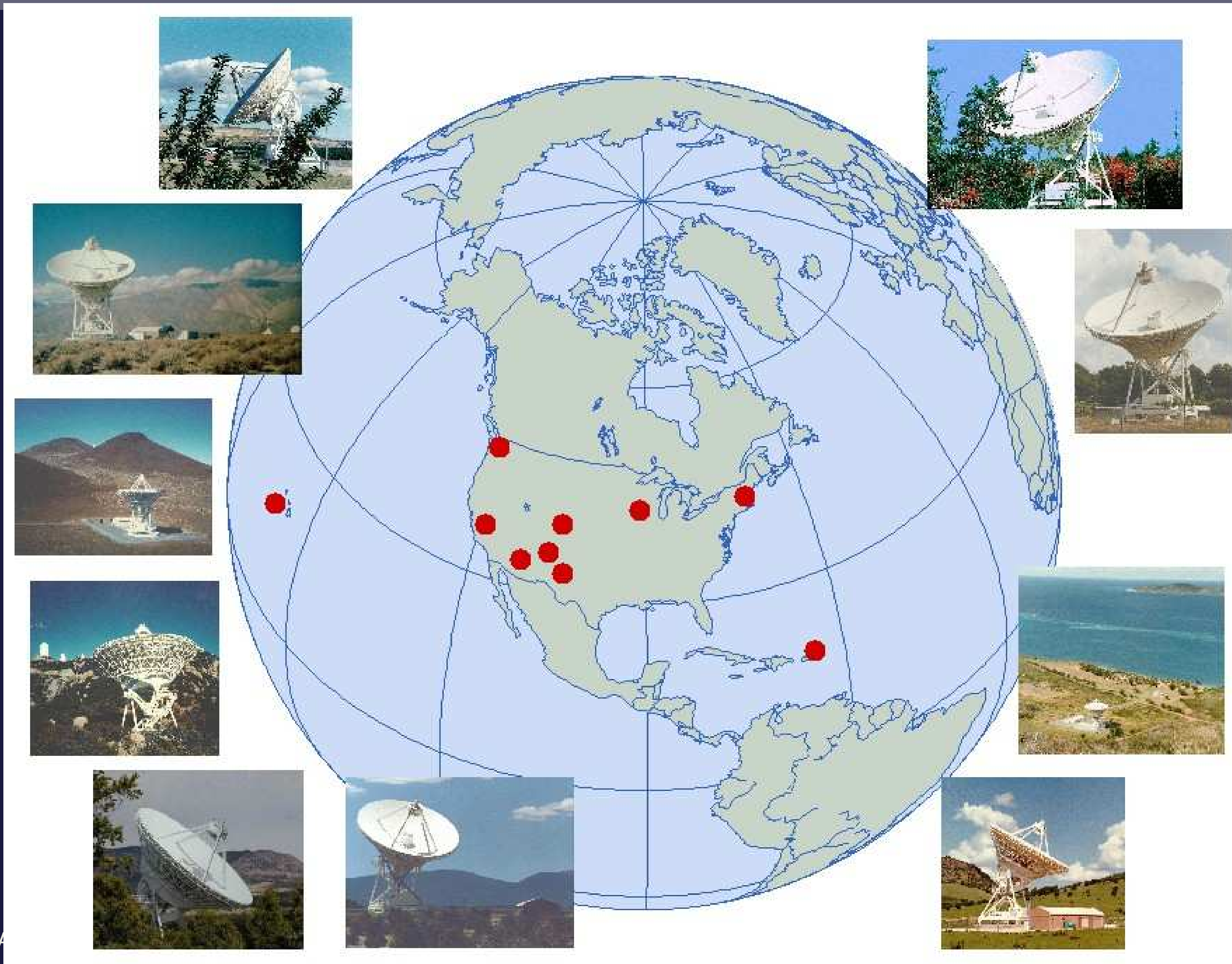
- Other science: velocity distributions, frame ties, NS cooling, etc.

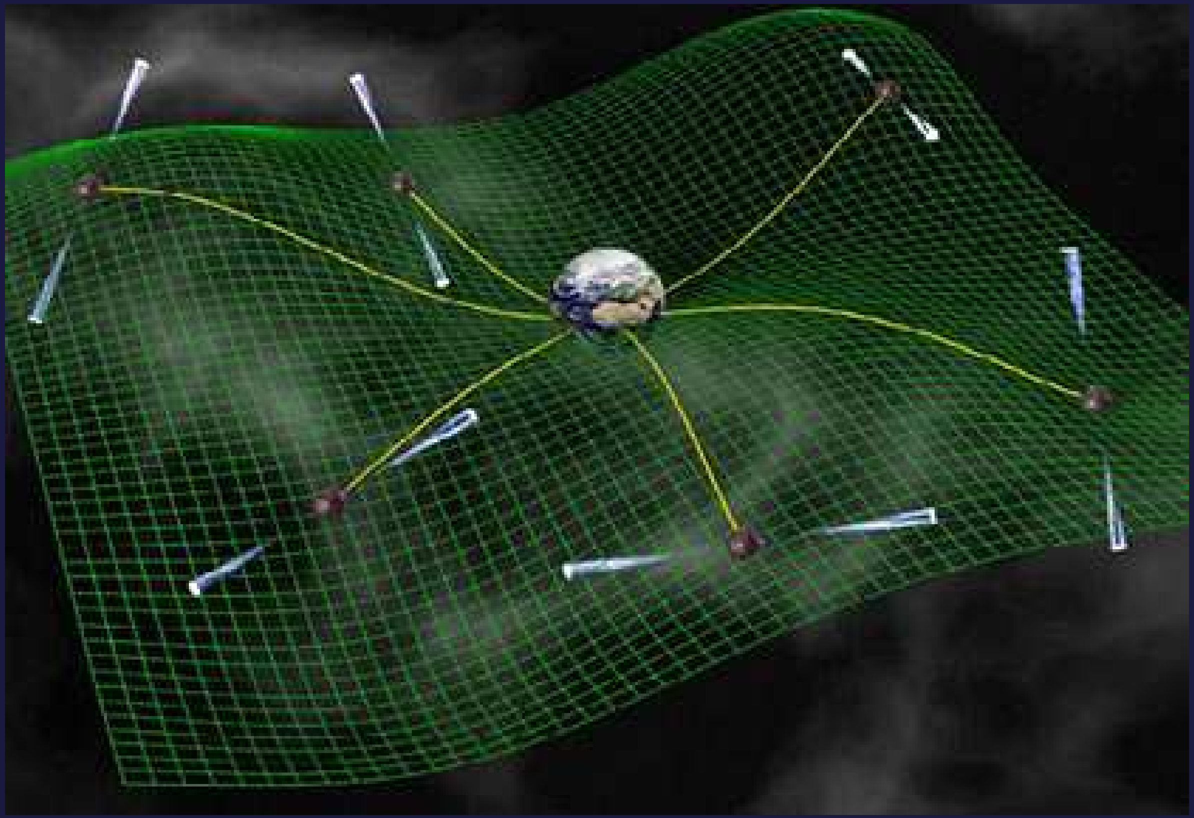
The VLBA: An Astrometry Machine



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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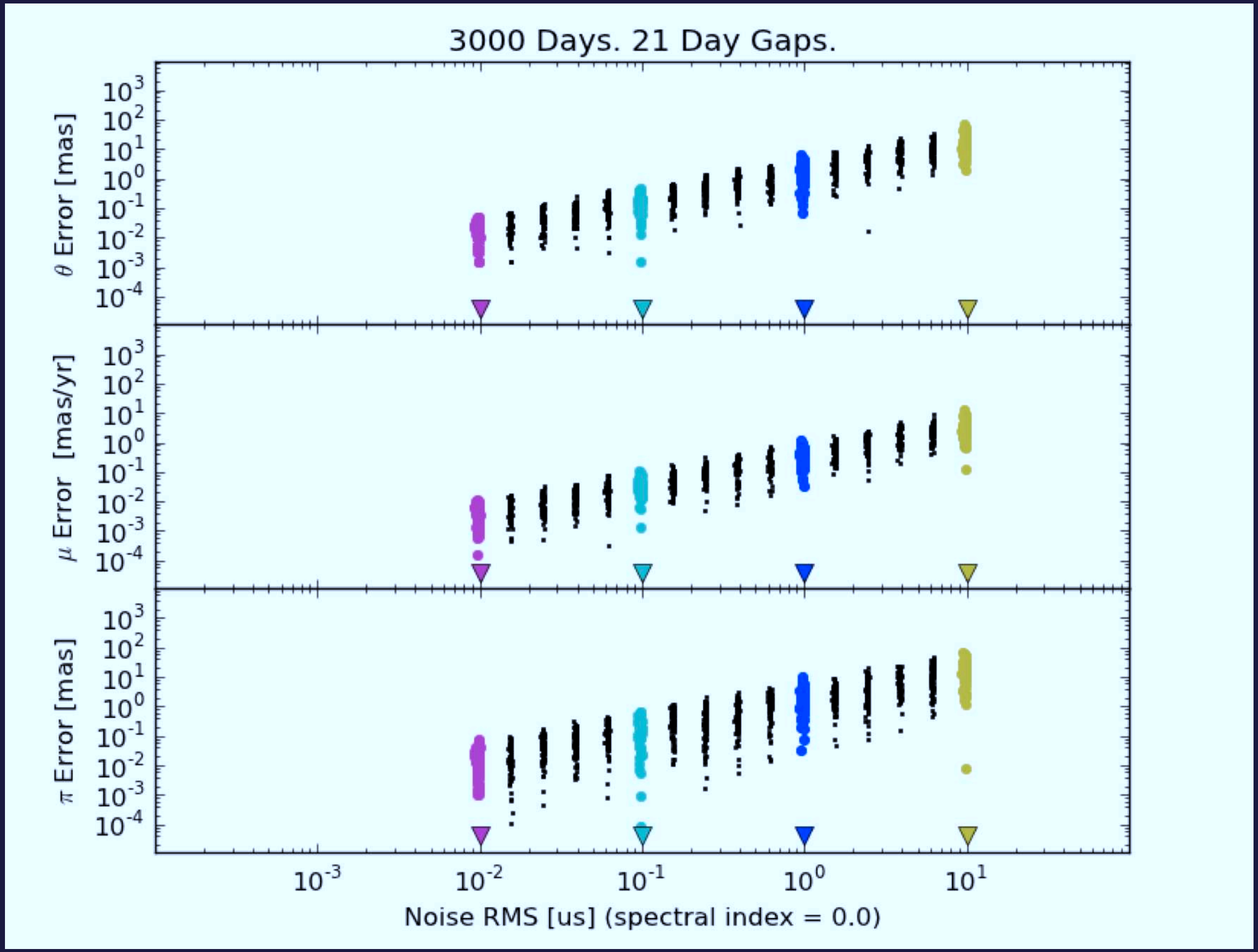

(Madison et al. 2012)

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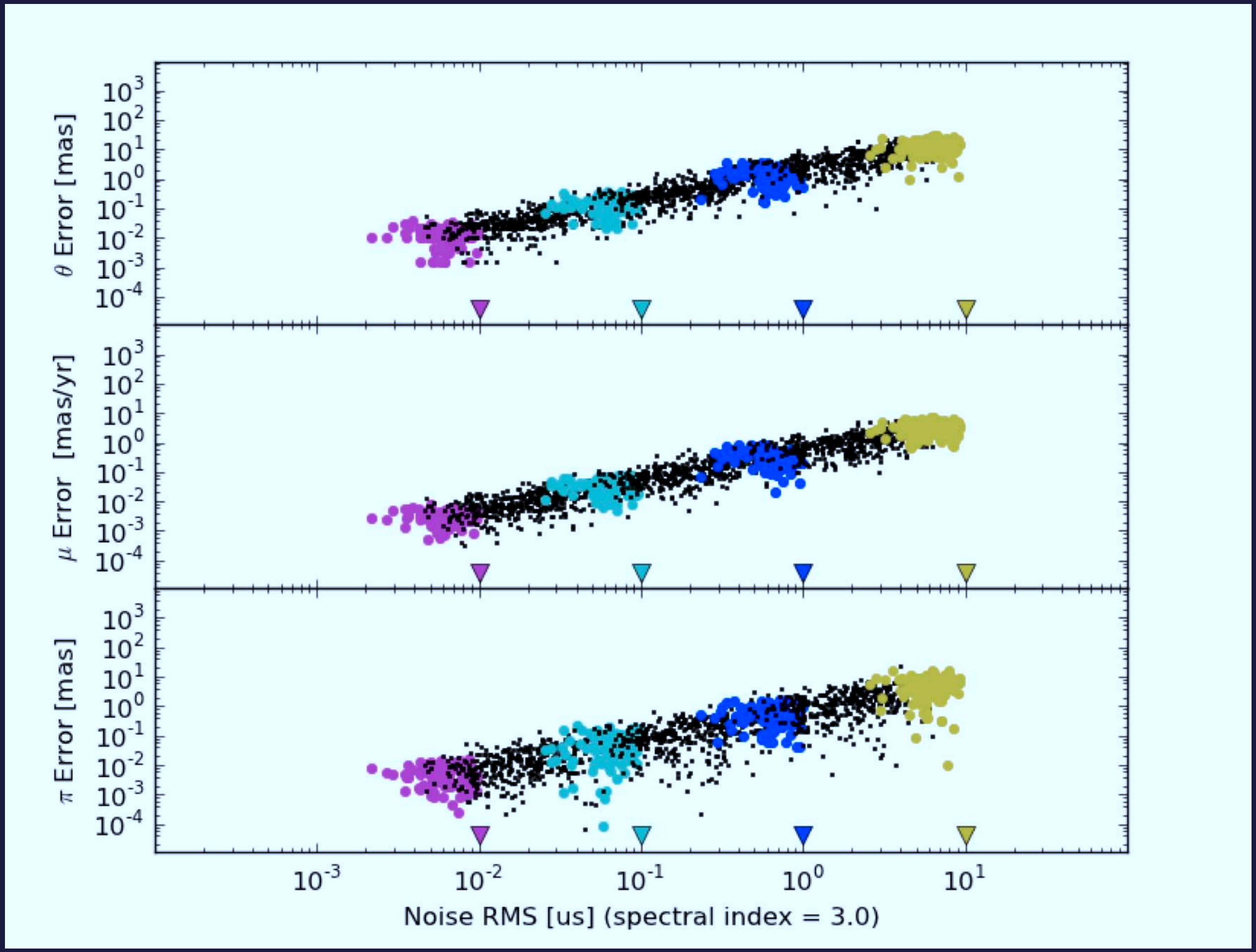

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- Effects are worse for redder noise.
- Effects worse for shorter data spans; reduced by denser sampling.

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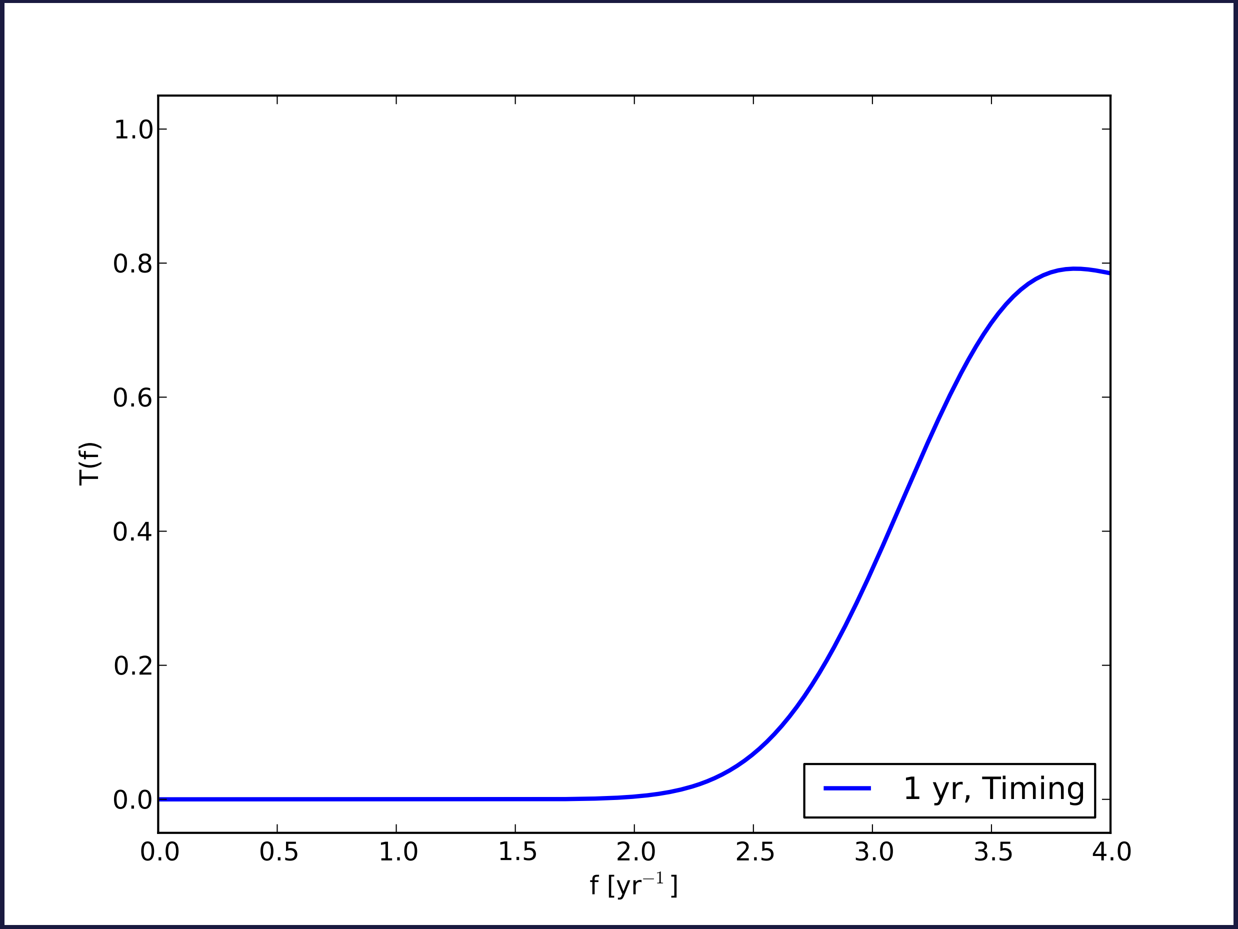

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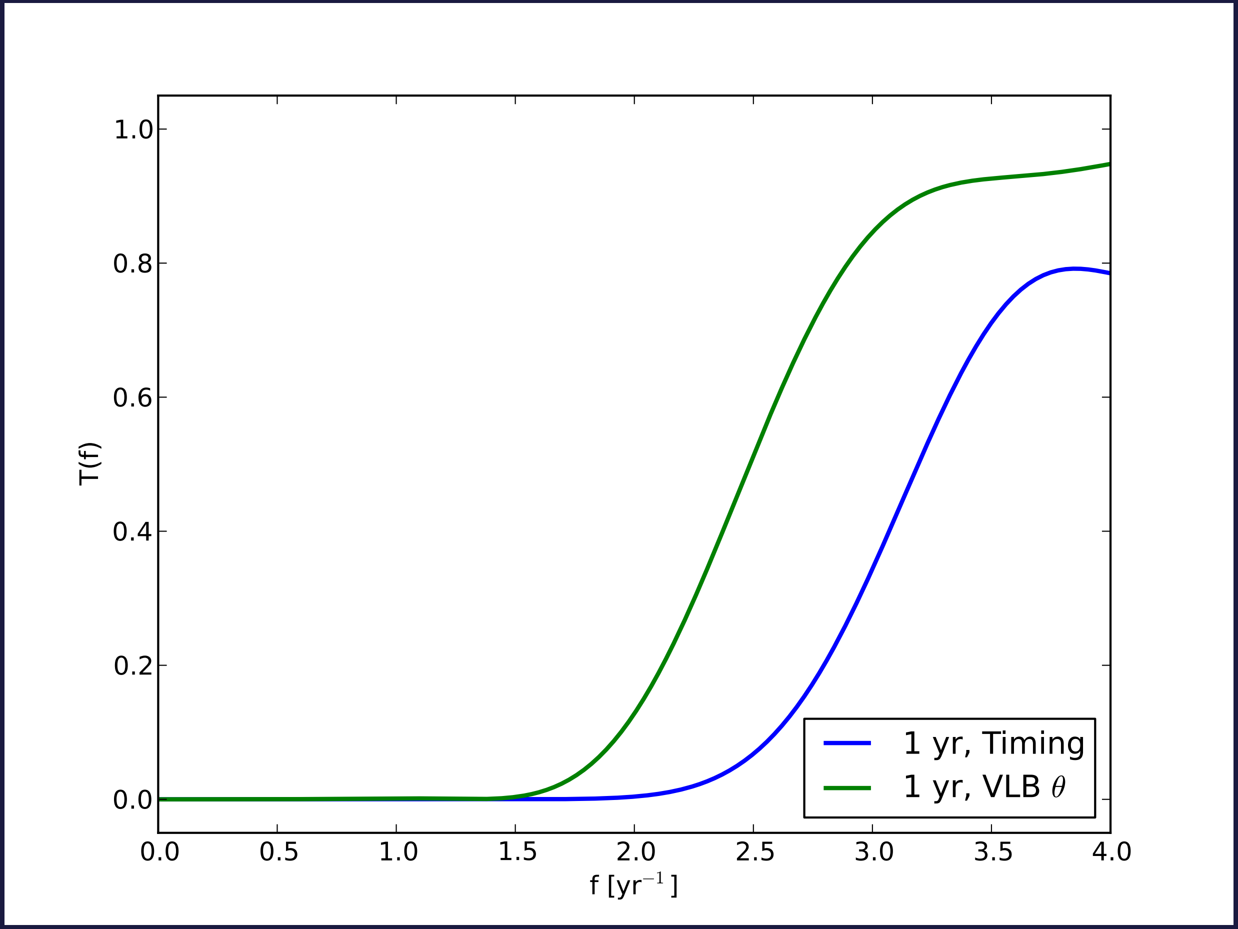

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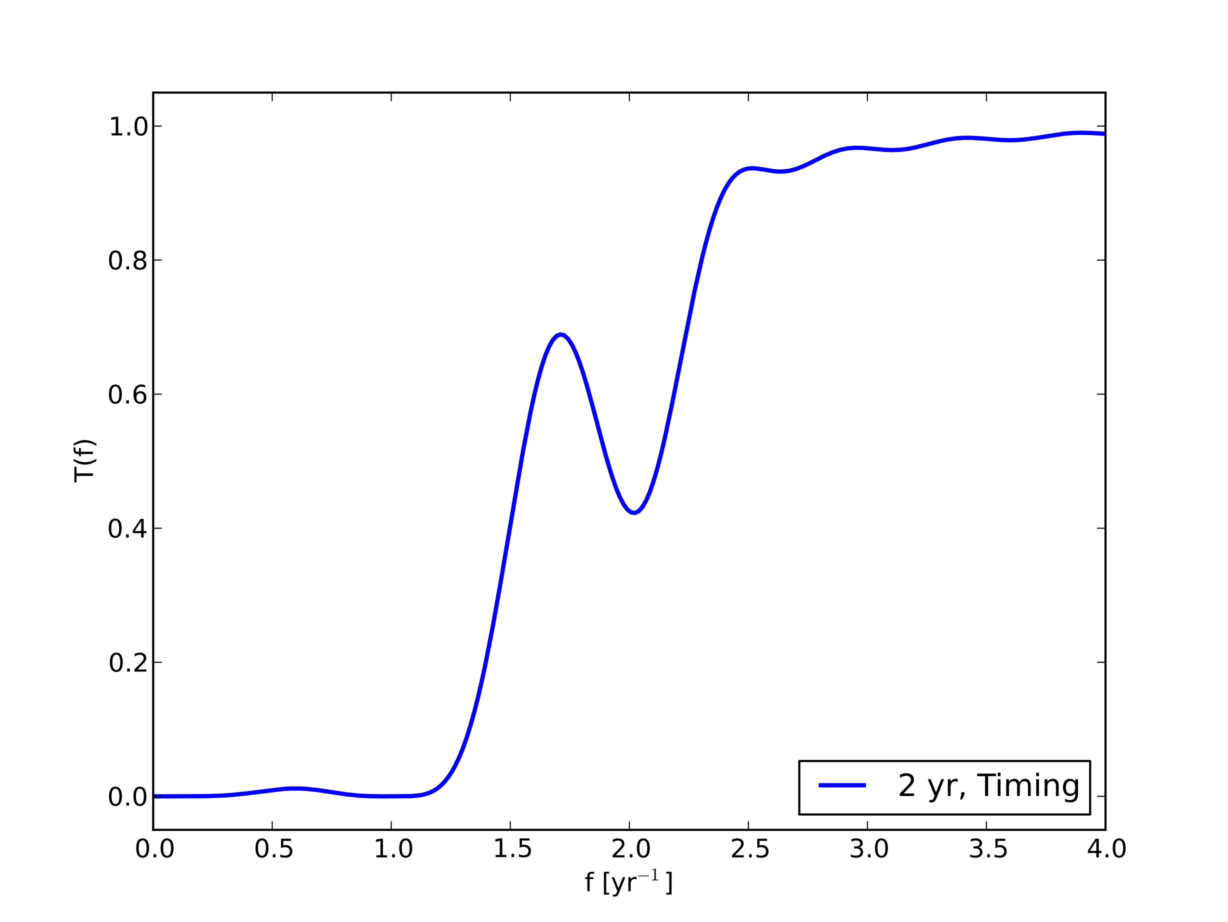

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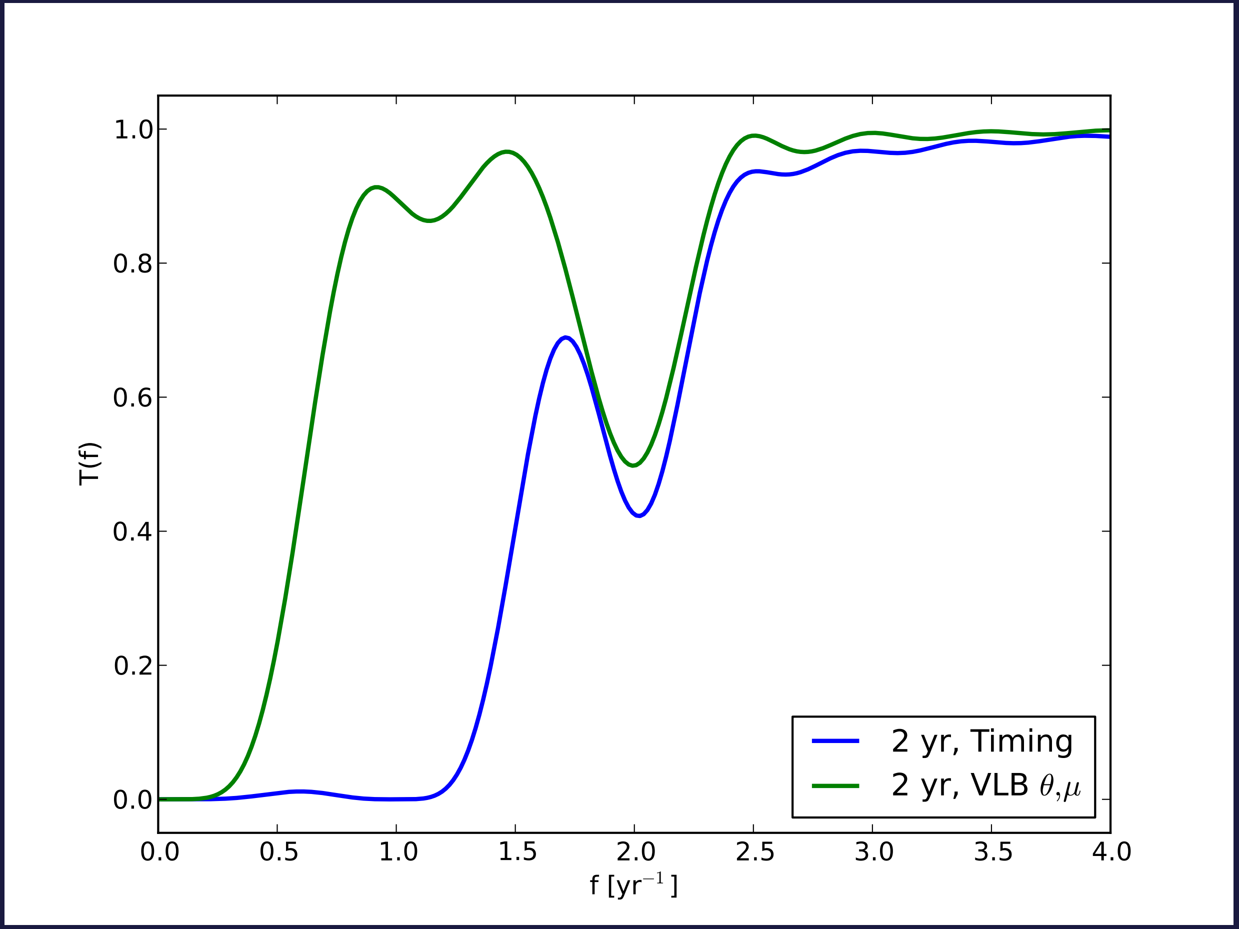

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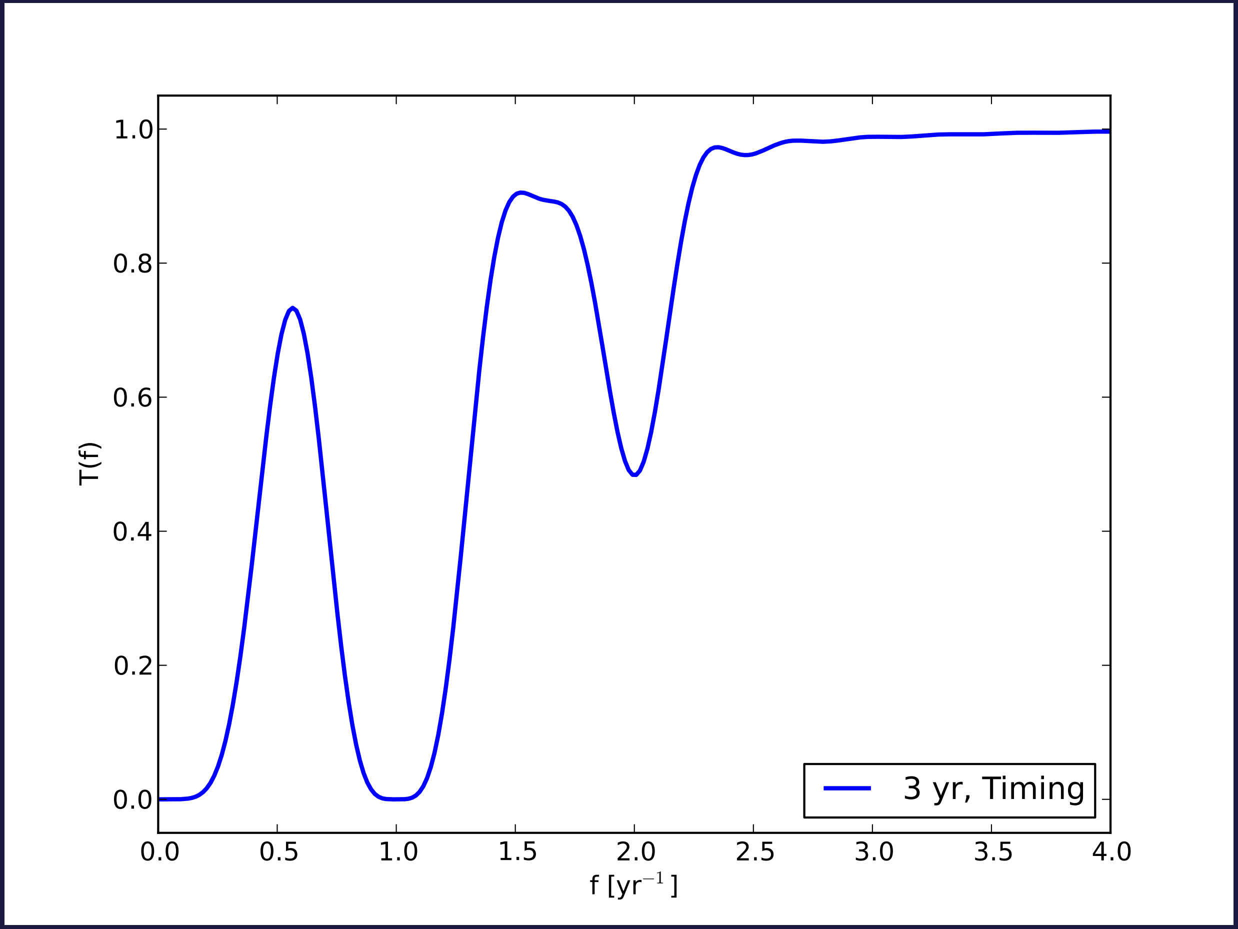

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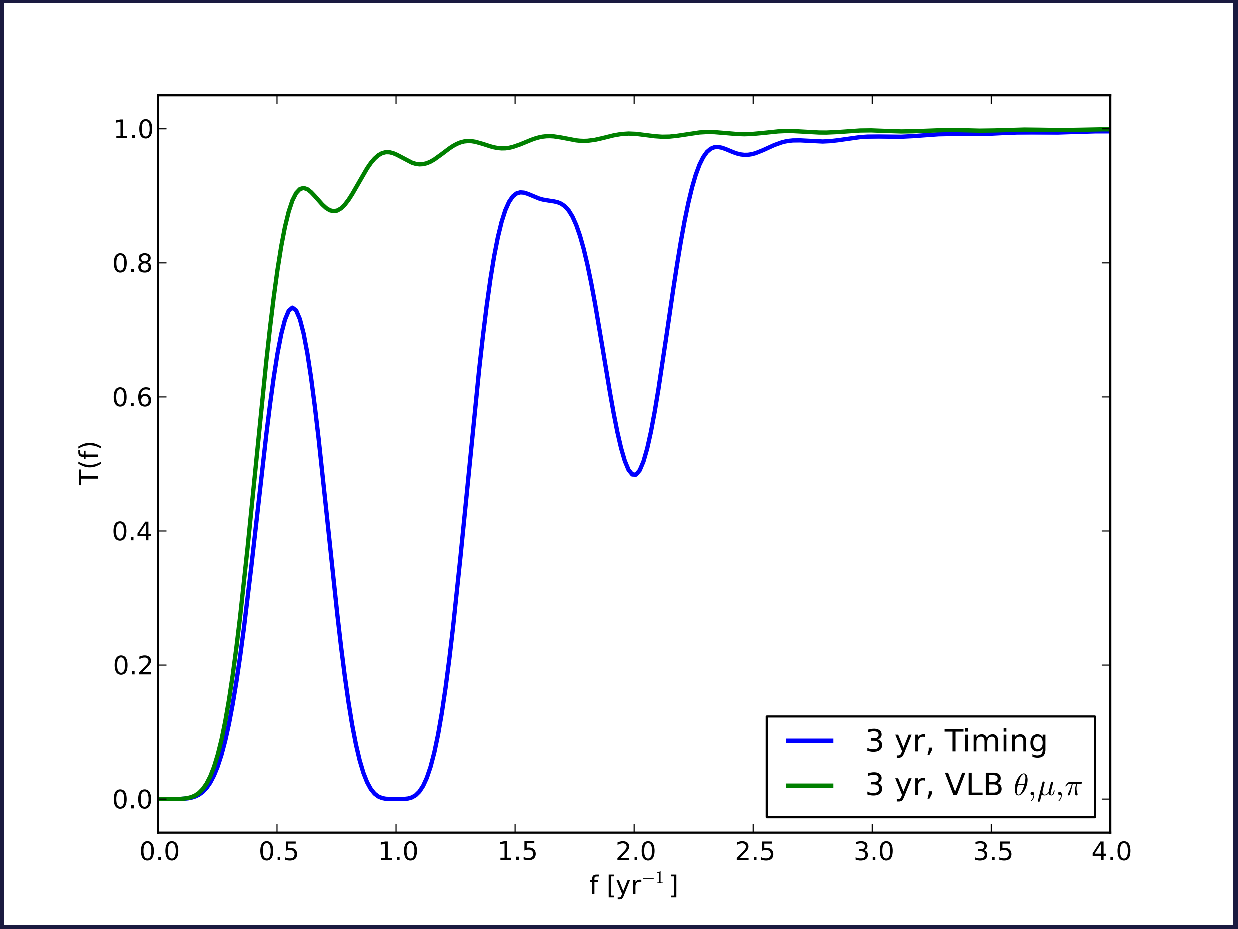

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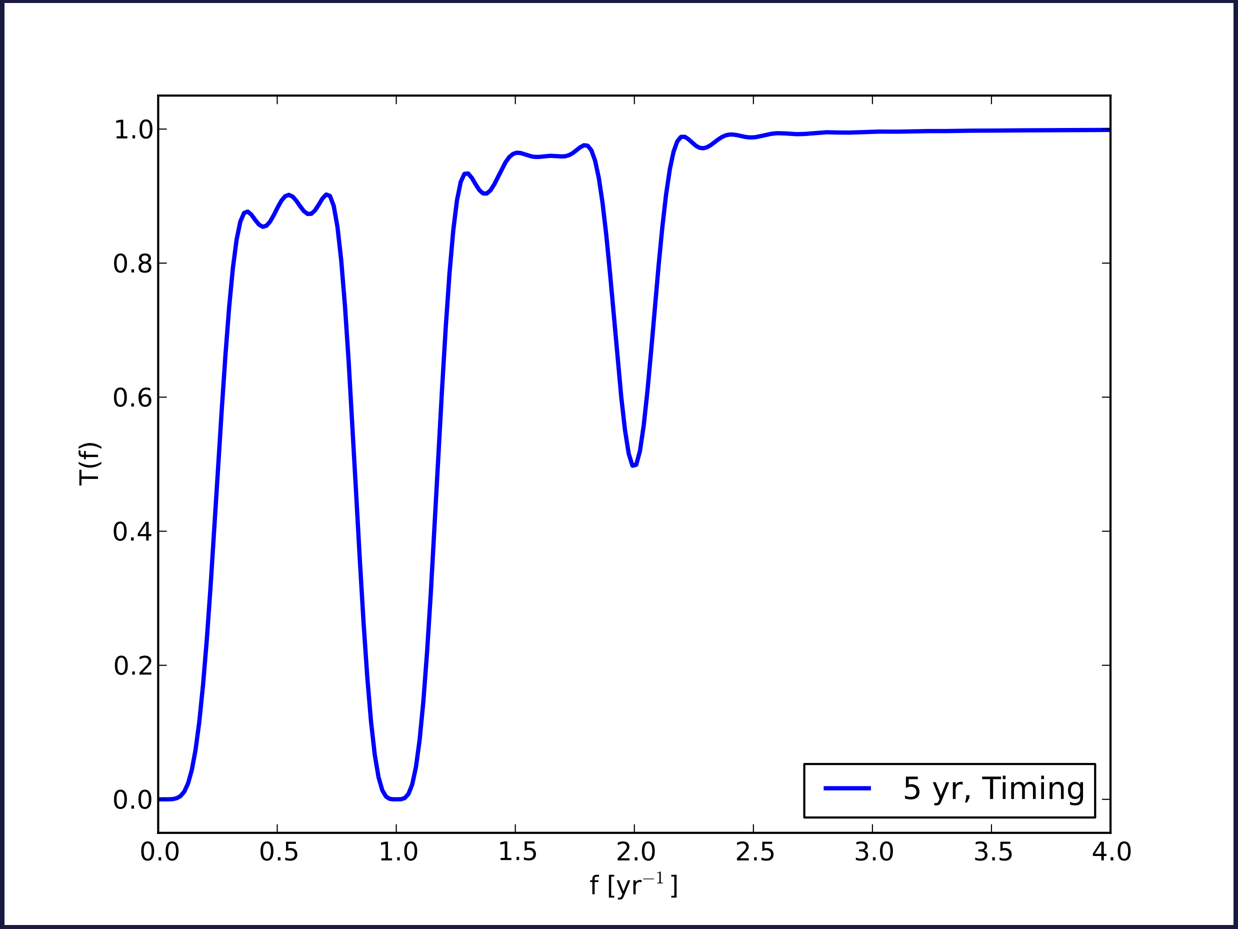

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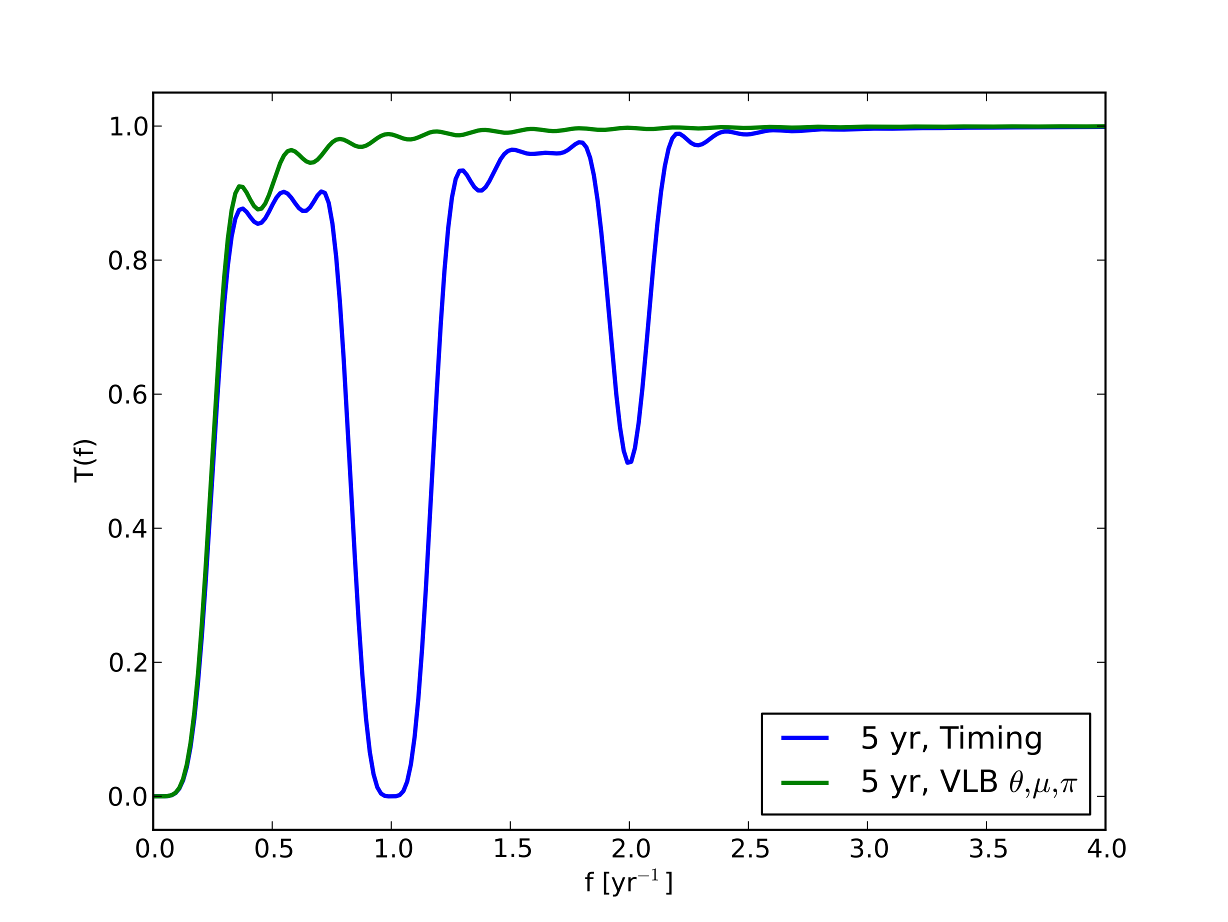

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- The path length difference between a pair of pulsars is a search parameter: parallaxes can vastly reduce the search space.
- Reference frame mismatch between ICRF and DE405 etc: may require an ensemble coordinate offset.

  $\Rightarrow$ Conceptually easy, but changes fitting procedure.

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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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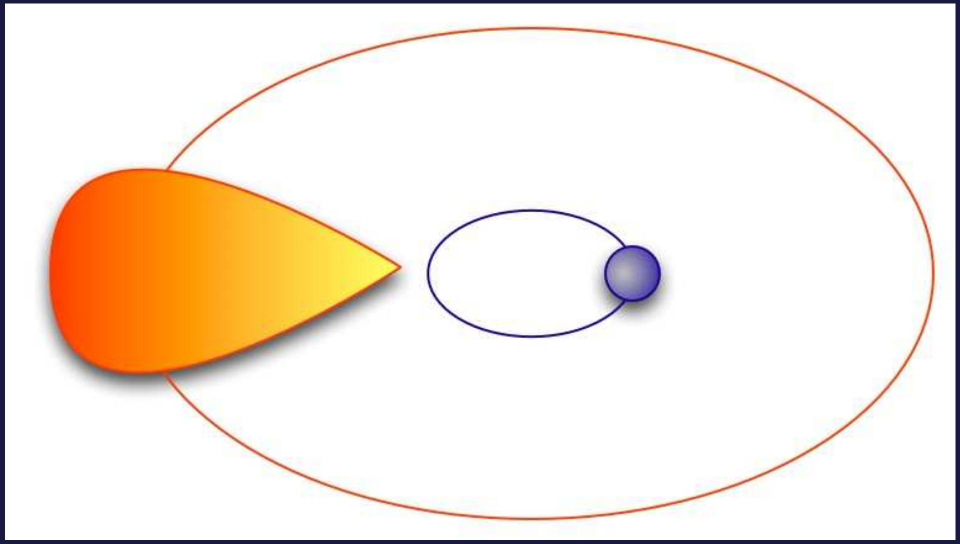
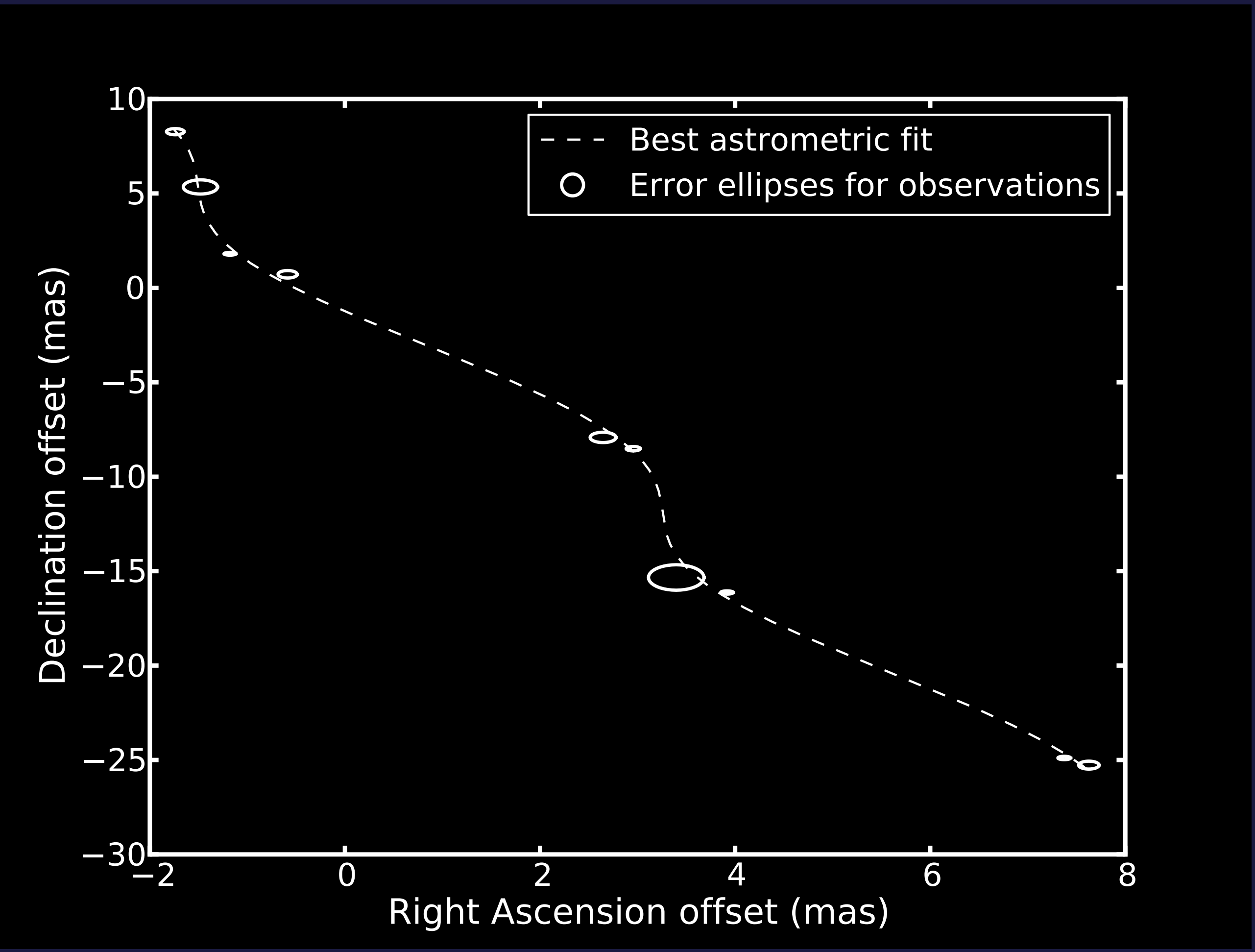
- P = 1.69 ms, Orbit = 4.75 hr.
- Variations in DM and P_{orbit}.
- Frequency dependent eclipses.
- X-ray emission shows orbital modulation.



PSR J1023+0038: VLBA astrometry



VLBA obs, 2008–2010:

- μ_a = 4.76 ± 0.03 mas/yr
- μ_d = -17.34 ± 0.04 mas/yr
- π = 0.73 ± 0.02 mas

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

(Deller et al. 2012)

PSR J1023+0038: NS mass estimate

- Optical observations: companion T ~ 5700 K.
- Photometry: physical size of Roche lobe as function of D.
- $D = 2.20\ (M_c/M_\odot)^{1/3}$ kpc (Thorstensen & Armstrong 2005).

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- Roche lobe not filled? If so, lower limit on mass.

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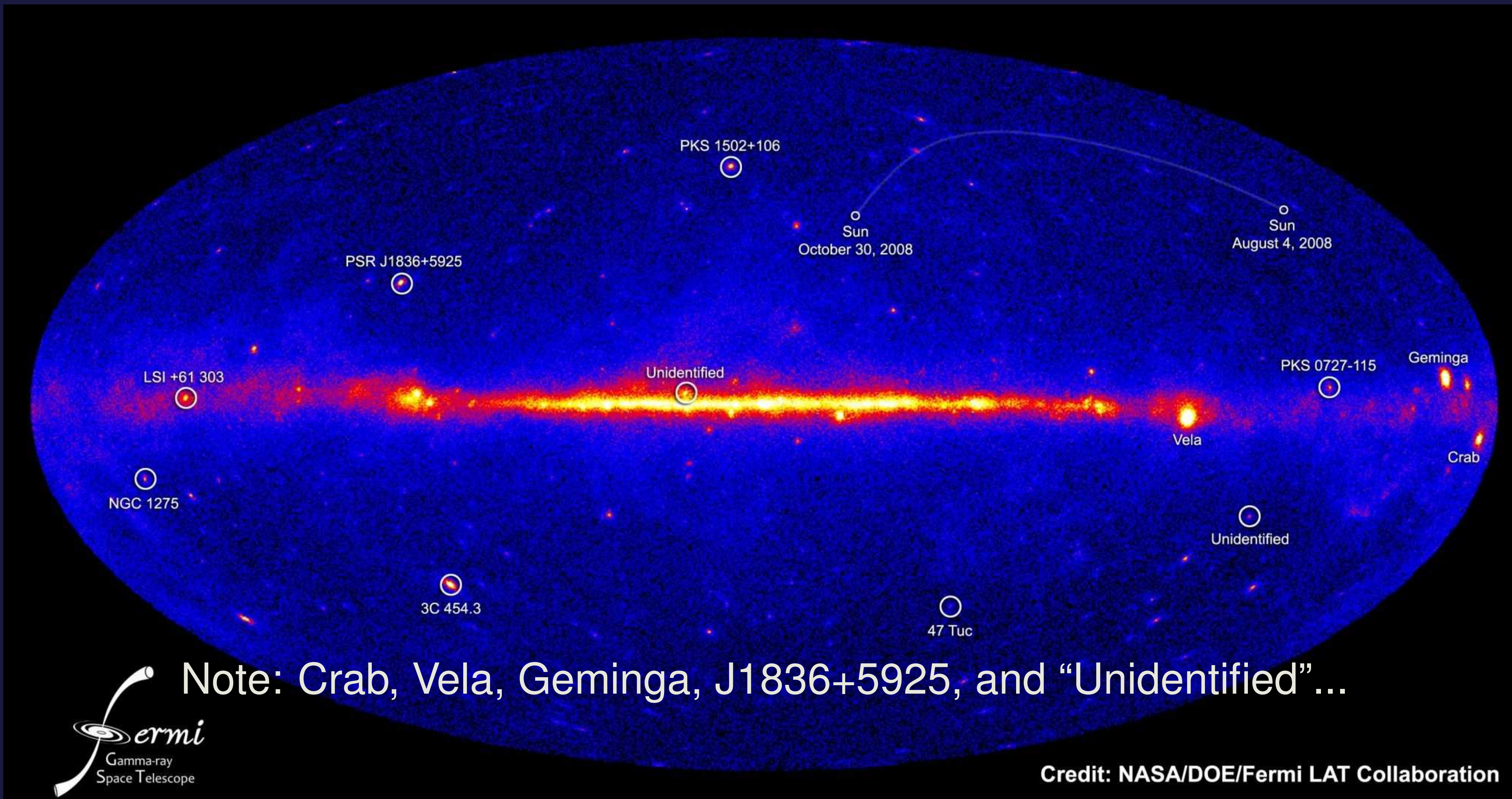
The Fermi gamma-ray space telescope

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

Fermi 3-month all-sky image



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

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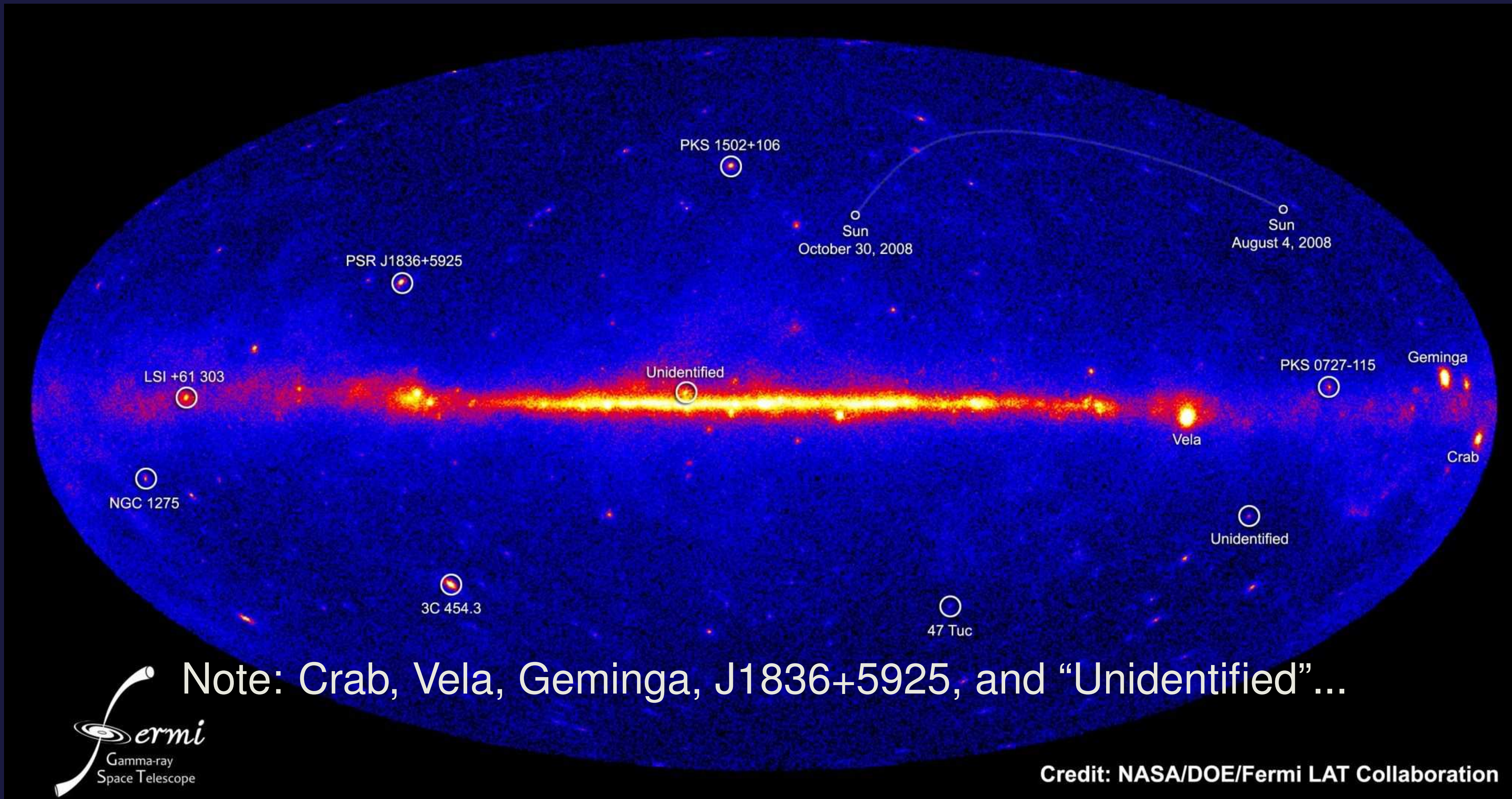

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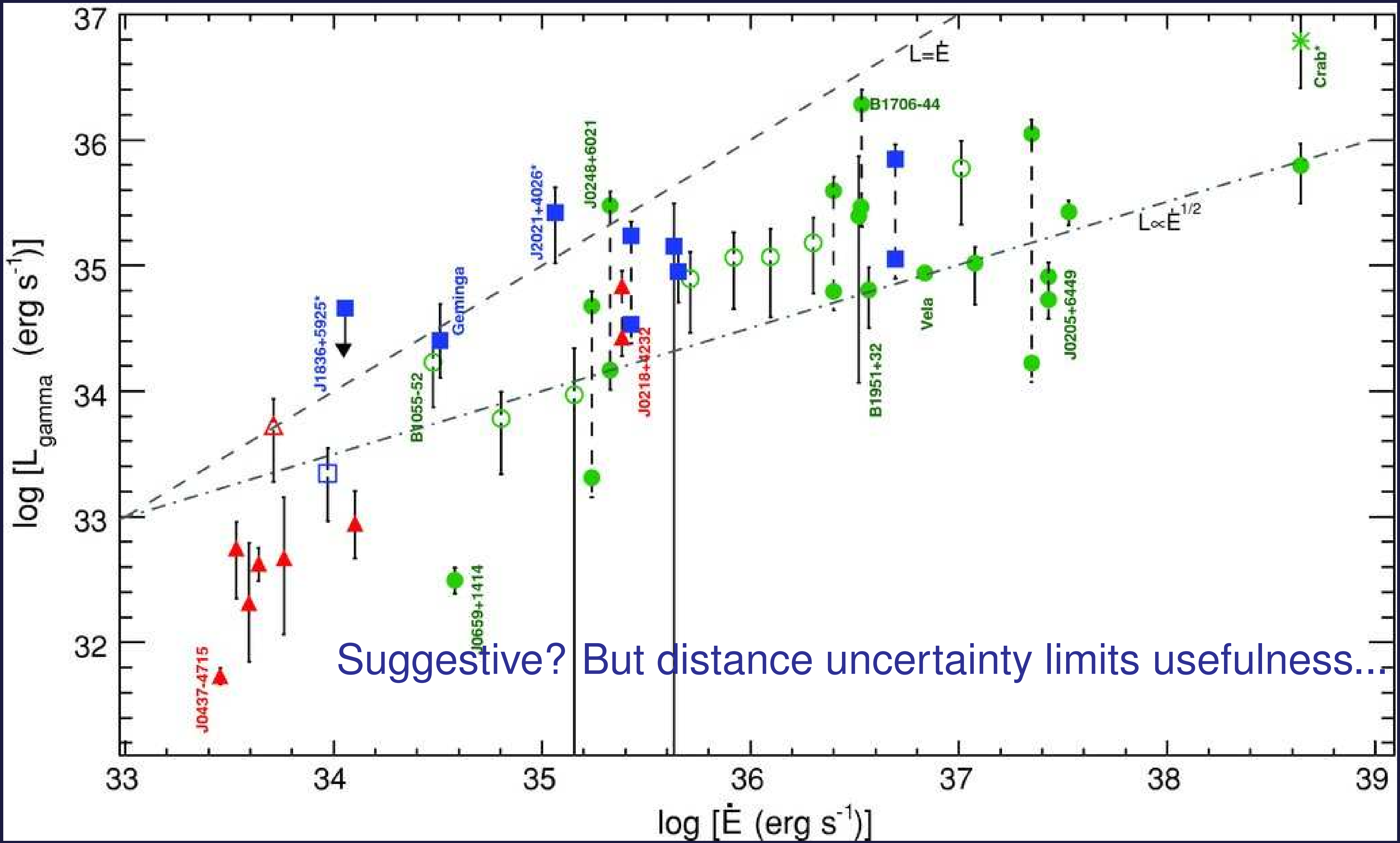
... Many new pulsars, especially recycled ones!

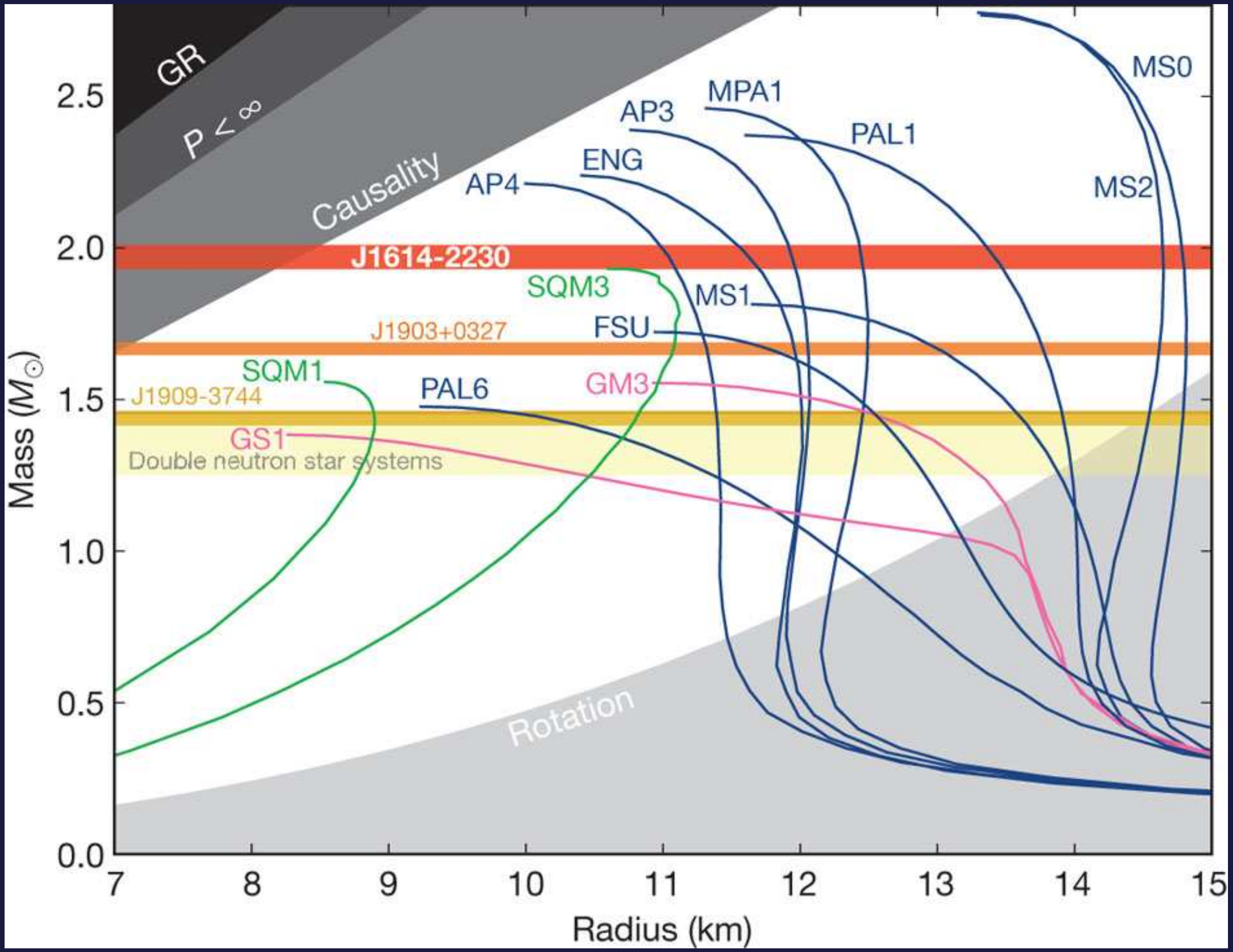
Gamma ray luminosity vs Spindown $\dot{E}$



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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- At D=1.2 kpc, L_γ is also $\gtrsim 100\%$ of $\dot{E}$.

... Happenstance? Coincidence?

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$\Rightarrow$ A precise distance may constrain the NS moment of inertia.

Ongoing astrometry programs

- Fermi/VLBA: A dozen γ-ray selected pulsars being followed. e.g., PSR J0751+1807: 4 epochs observed.

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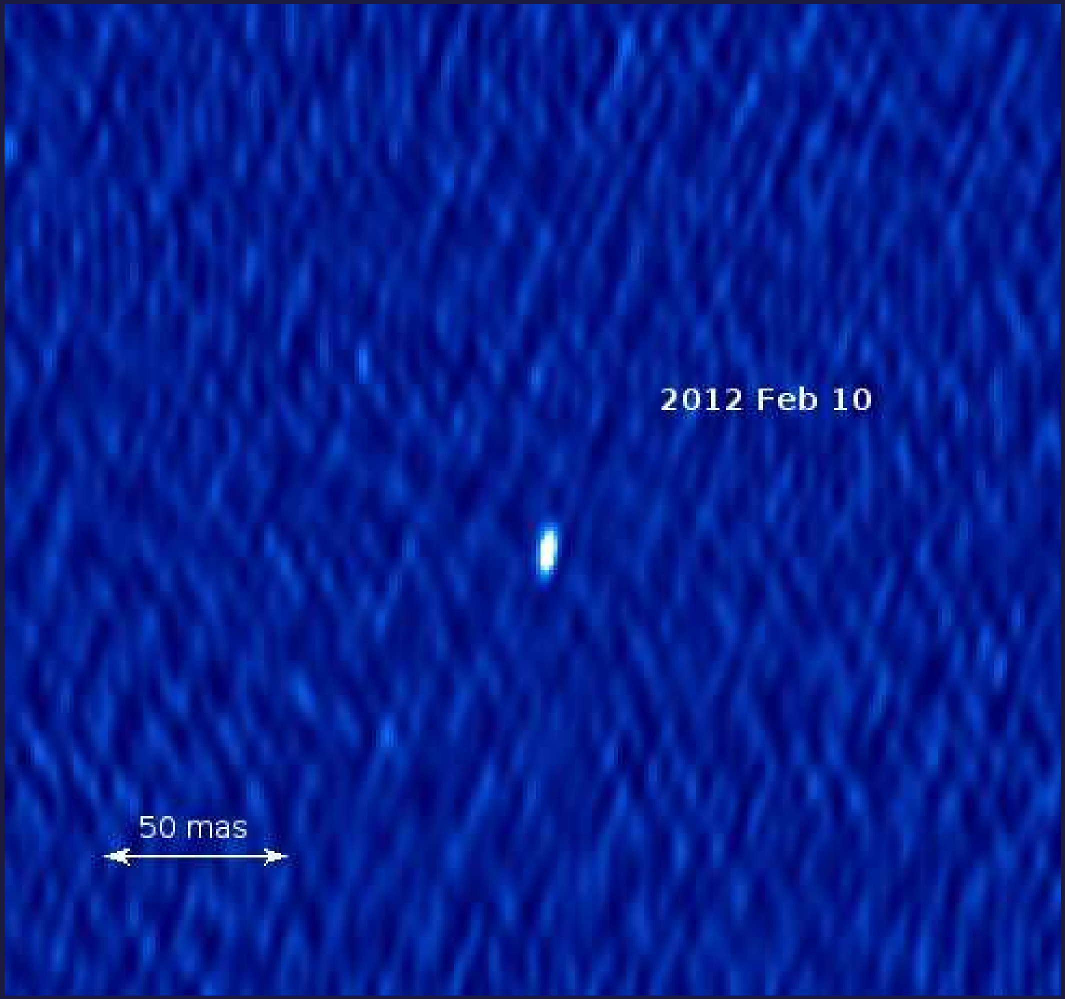

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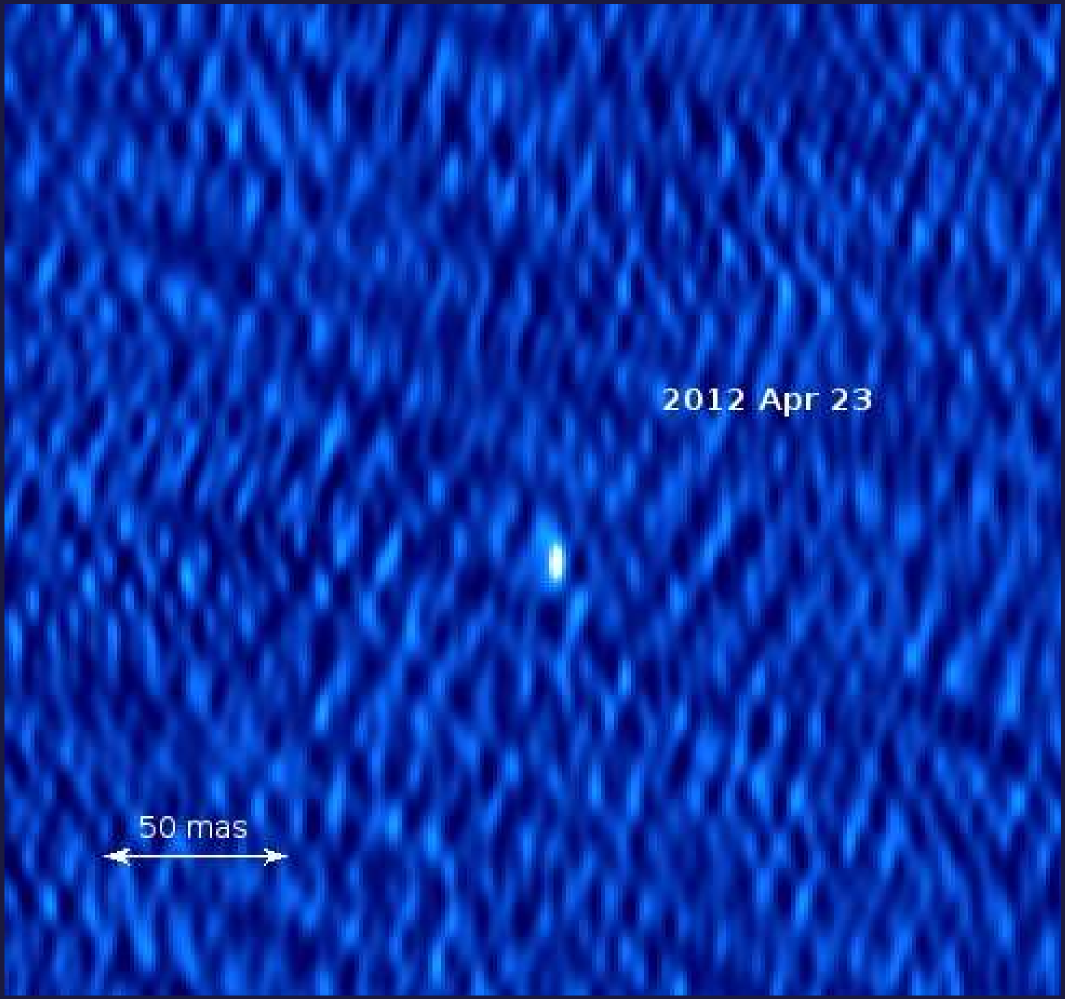

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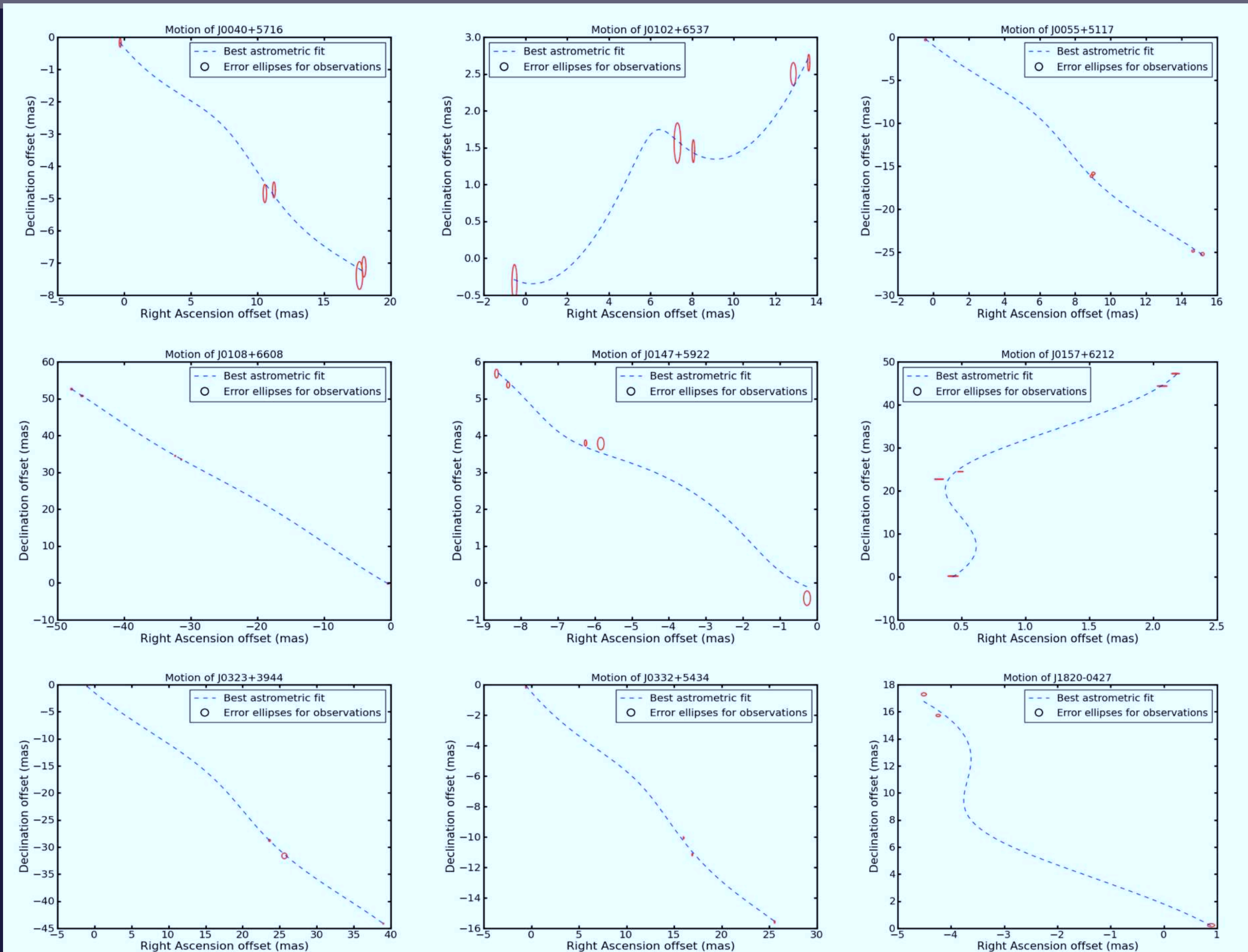
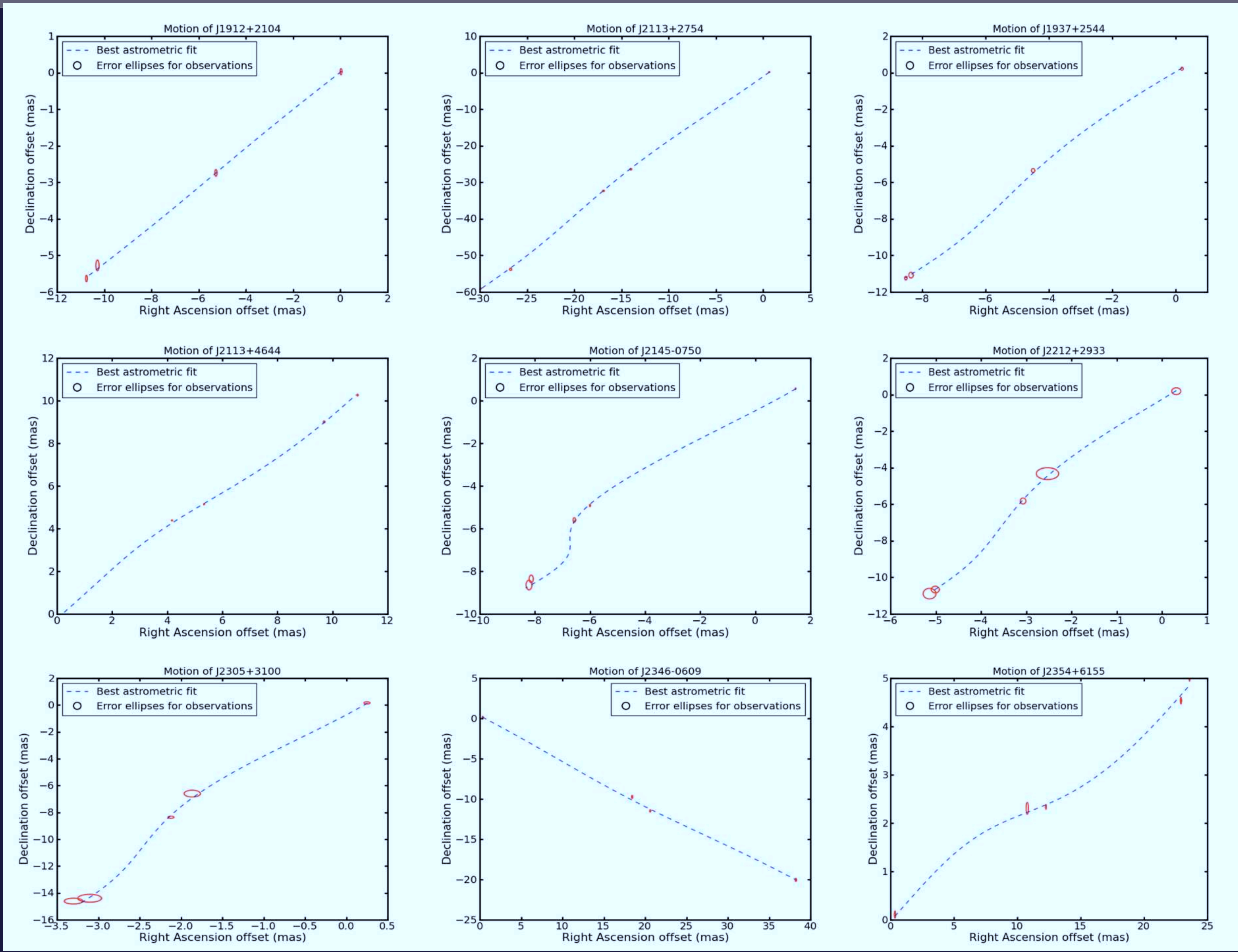
  - 3–5 epochs observed (of 8) on 60 pulsars at 512 Mbps.
  - Preliminary parallaxes down to 10 μas for best 4.
  - At least 55 of 60 look promising...
  - Can expand sample once 2 Gbps bit rates available at VLBA.

`https://safe.nrao.edu/vlba/psrpi/`

PSRPi: a preview of coming attractions



PSRPi: more coming attractions



A distance measuring service

Is <u>YOUR</u> 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!

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Collaborators and Acknowledgements

VLBA astrometry collaboration:
Adam Deller, Walter Brisken, Joseph Lazio, James Cordes, Miller Goss, et al.

https://safe.nrao.edu/vlba/psrpi/

Fermi pulsar collaboration:
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/