Pulsar Timing Arrays

Jason Hessels

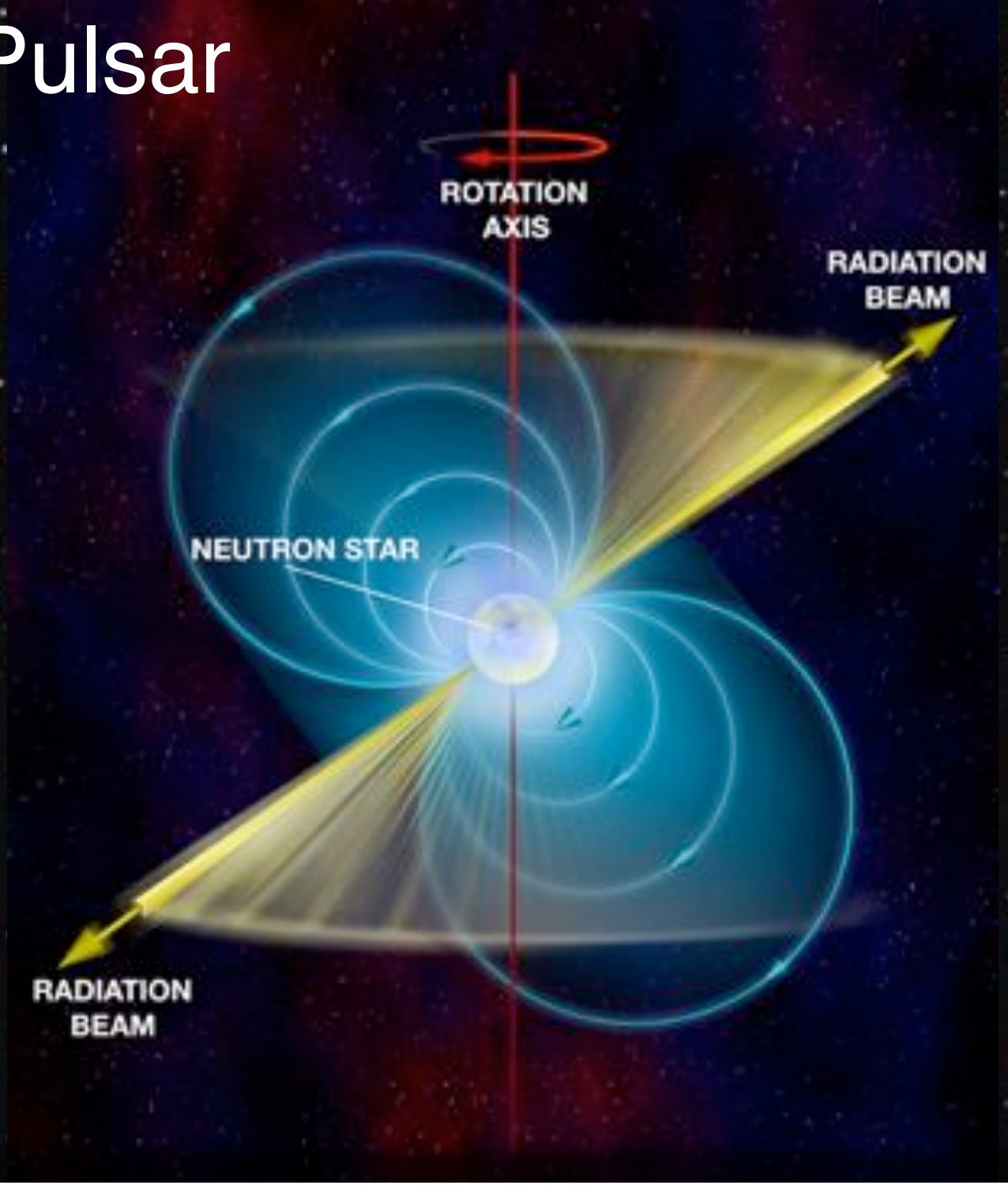
ASTRON / UvA

Outline

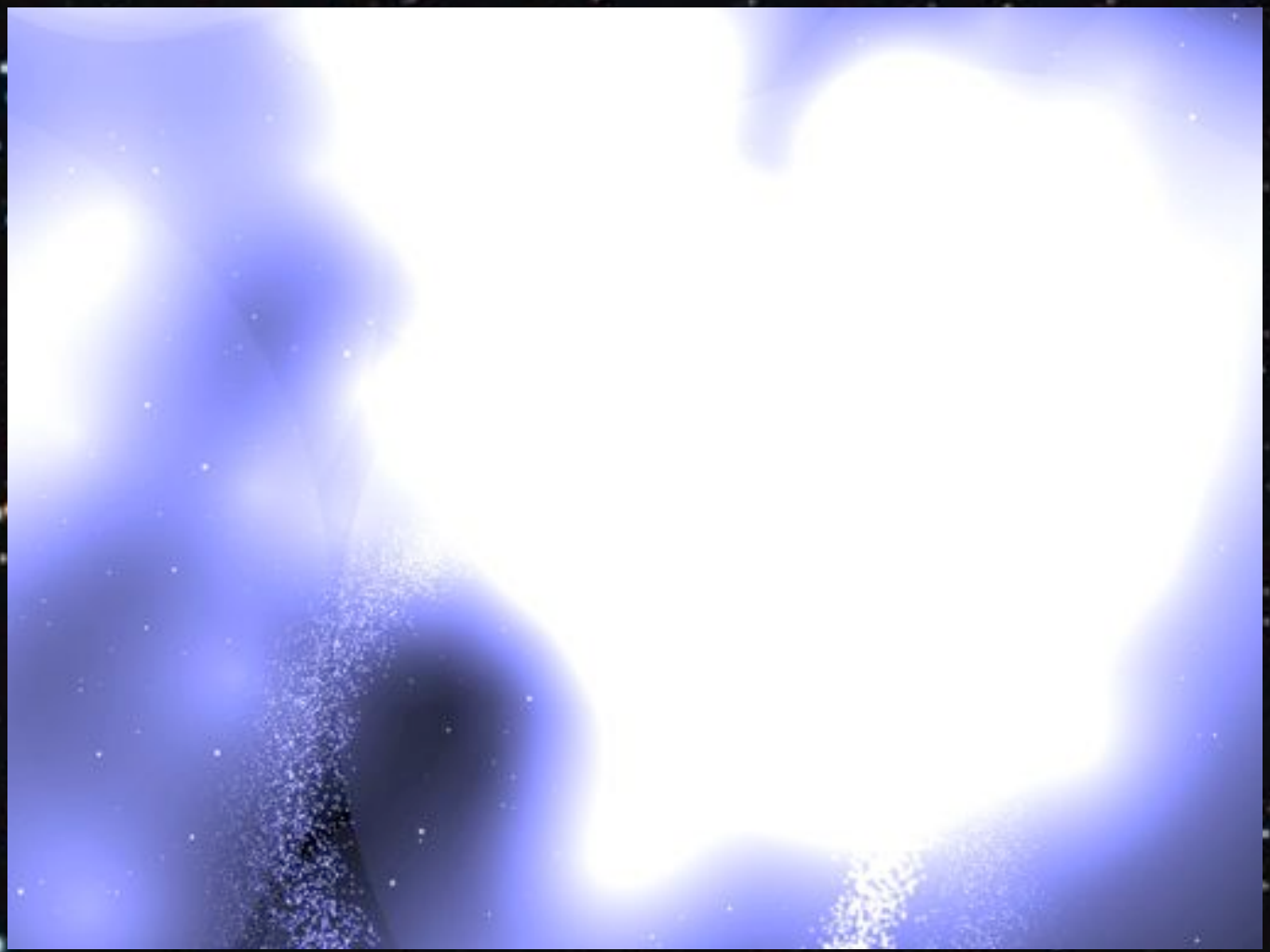
- Pulsar Timing
- Detecting GWs
- PTA Consortia
- Future Prospects

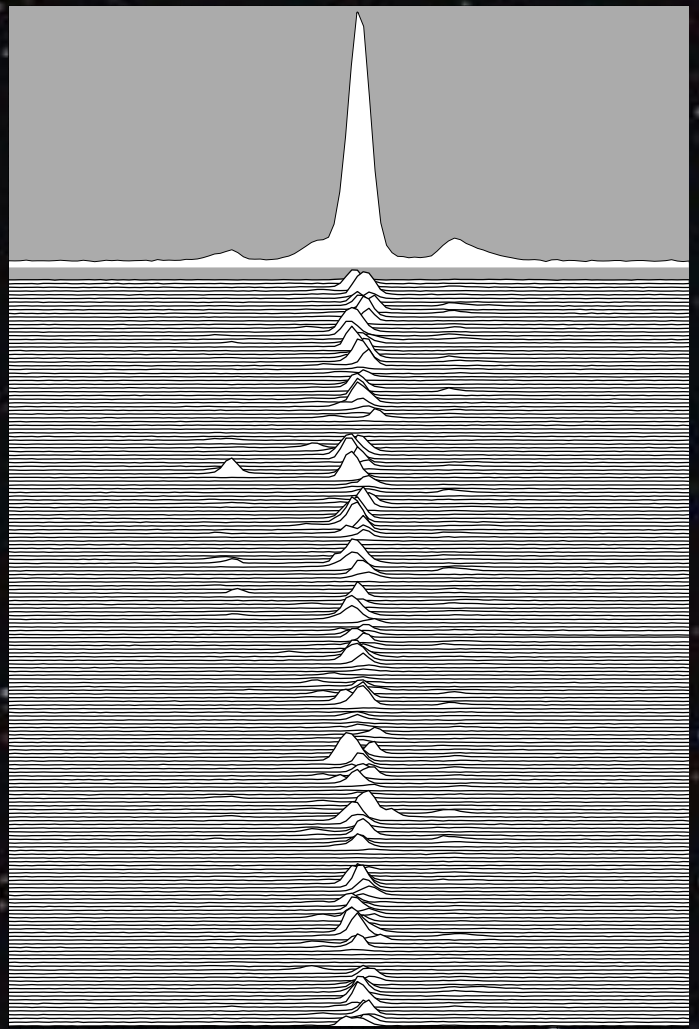
Pulsar Timing

Radio Pulsar



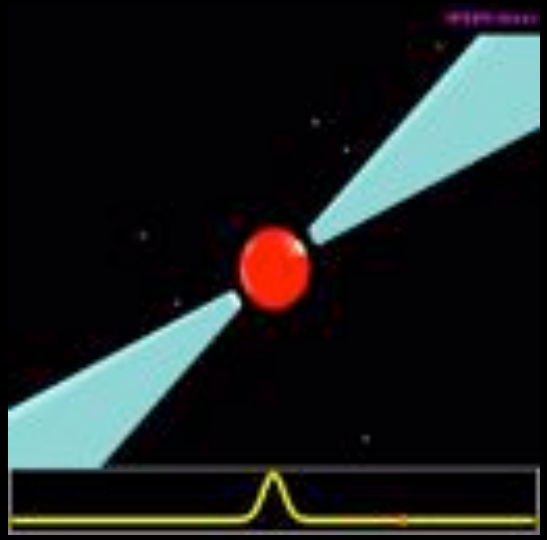
Pulsars are high-precision clocks



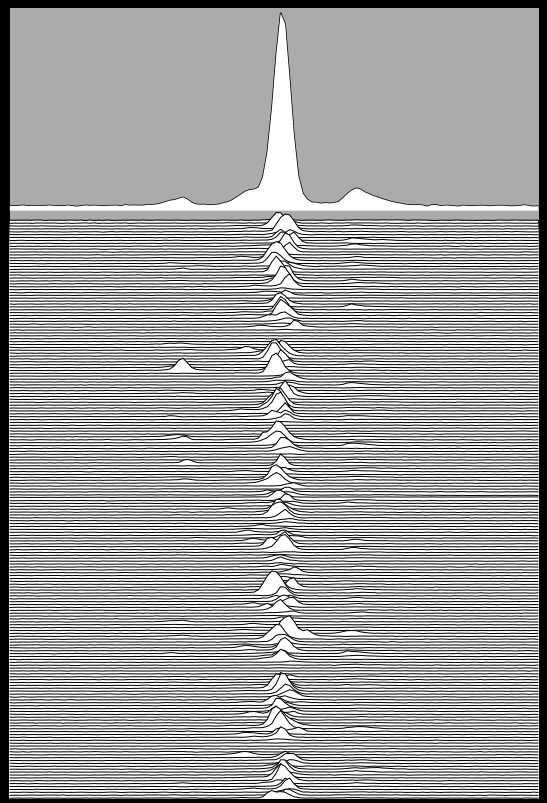


Some pulsars spin 100s of times a second making them high-precision clocks

Pulsar Timing
Using pulsars as precision clocks



Collect pulses

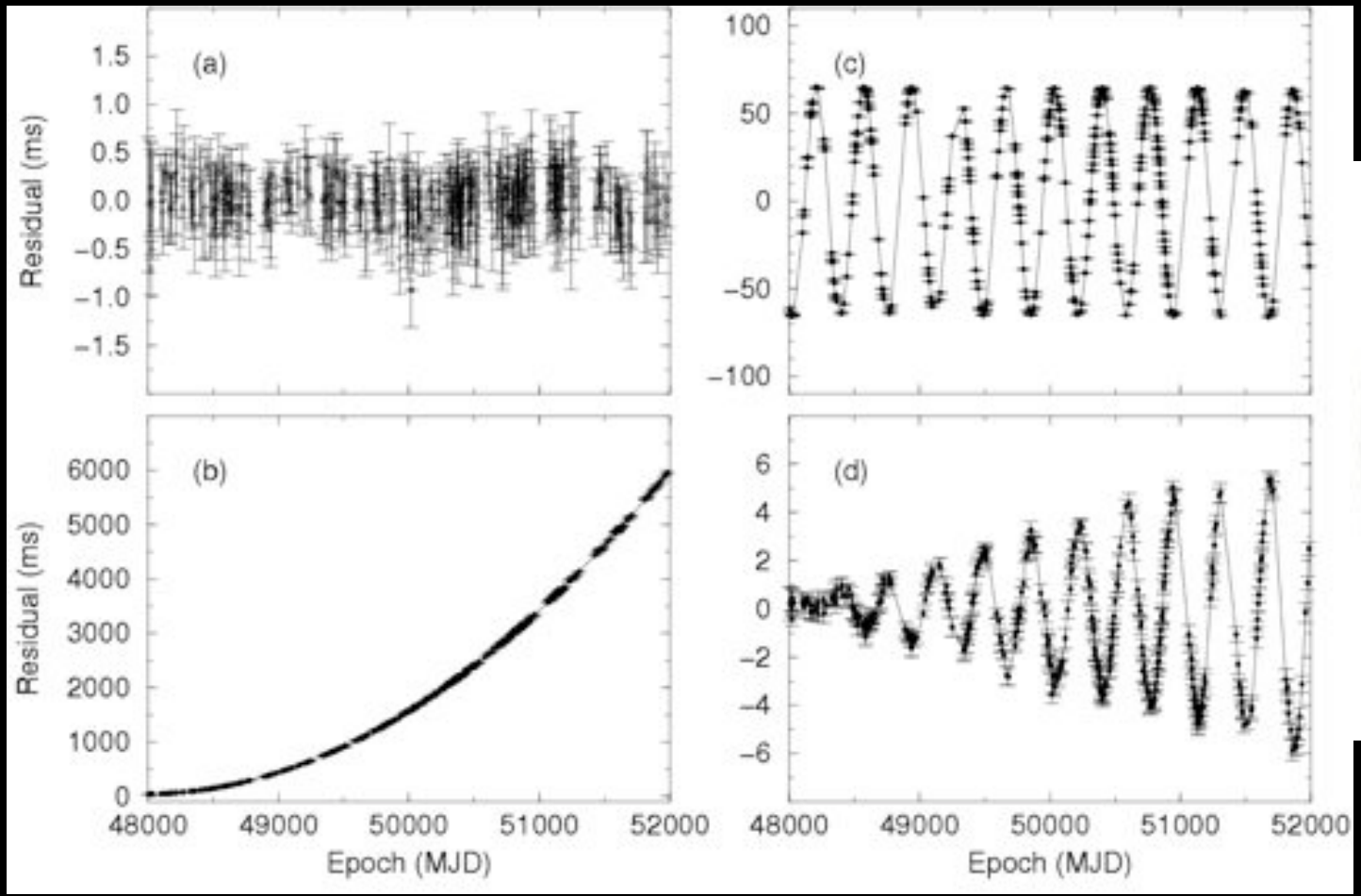


Dedisperse, fold and cross-correlate with template

54255.12312545242333
54255.26434435234533
54255.31235245458999
54255.35137456234677
54255.44184565433555
54255.50012342346888

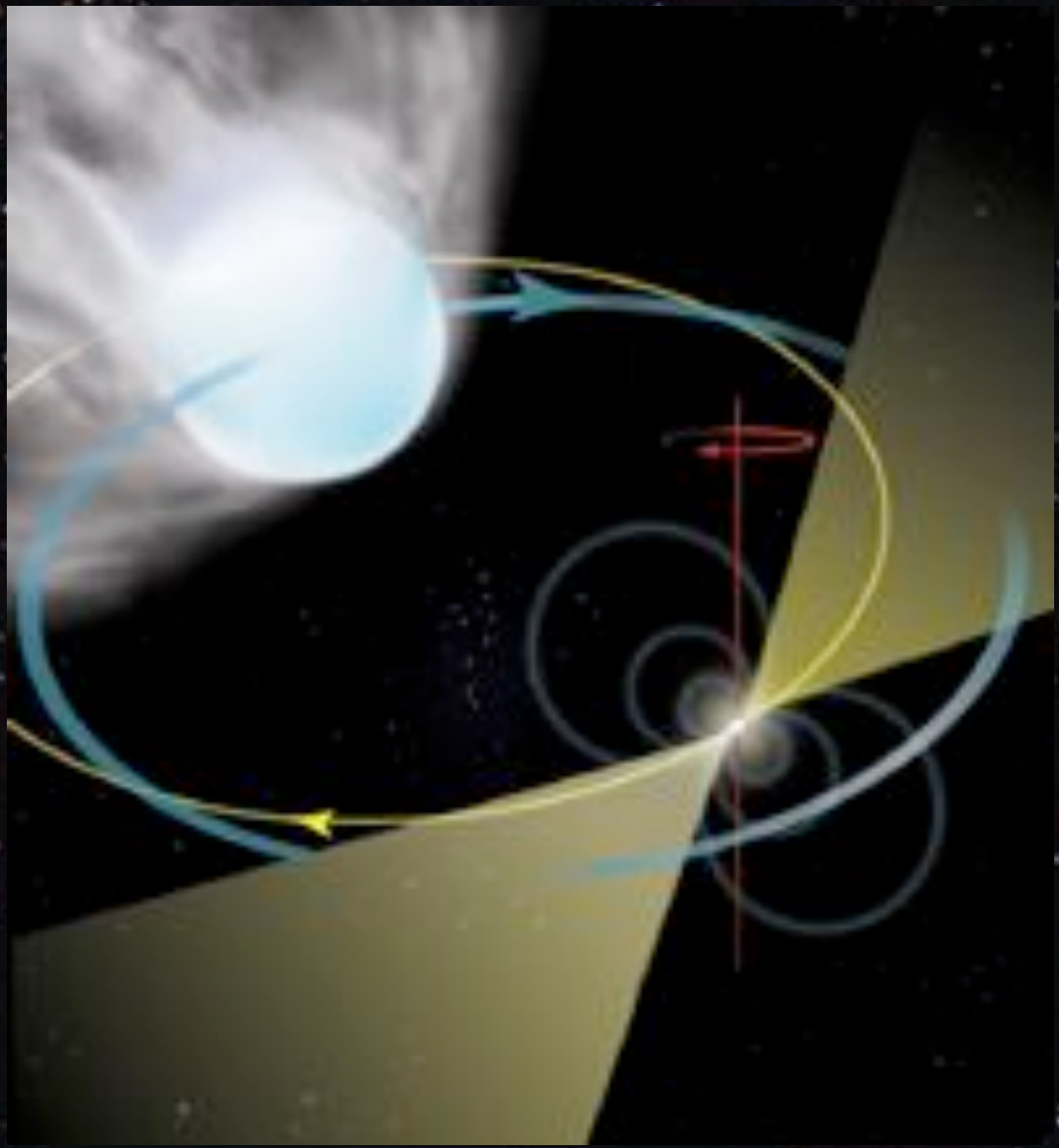
Times of arrival (TOAs)

Pulsar Timing Model

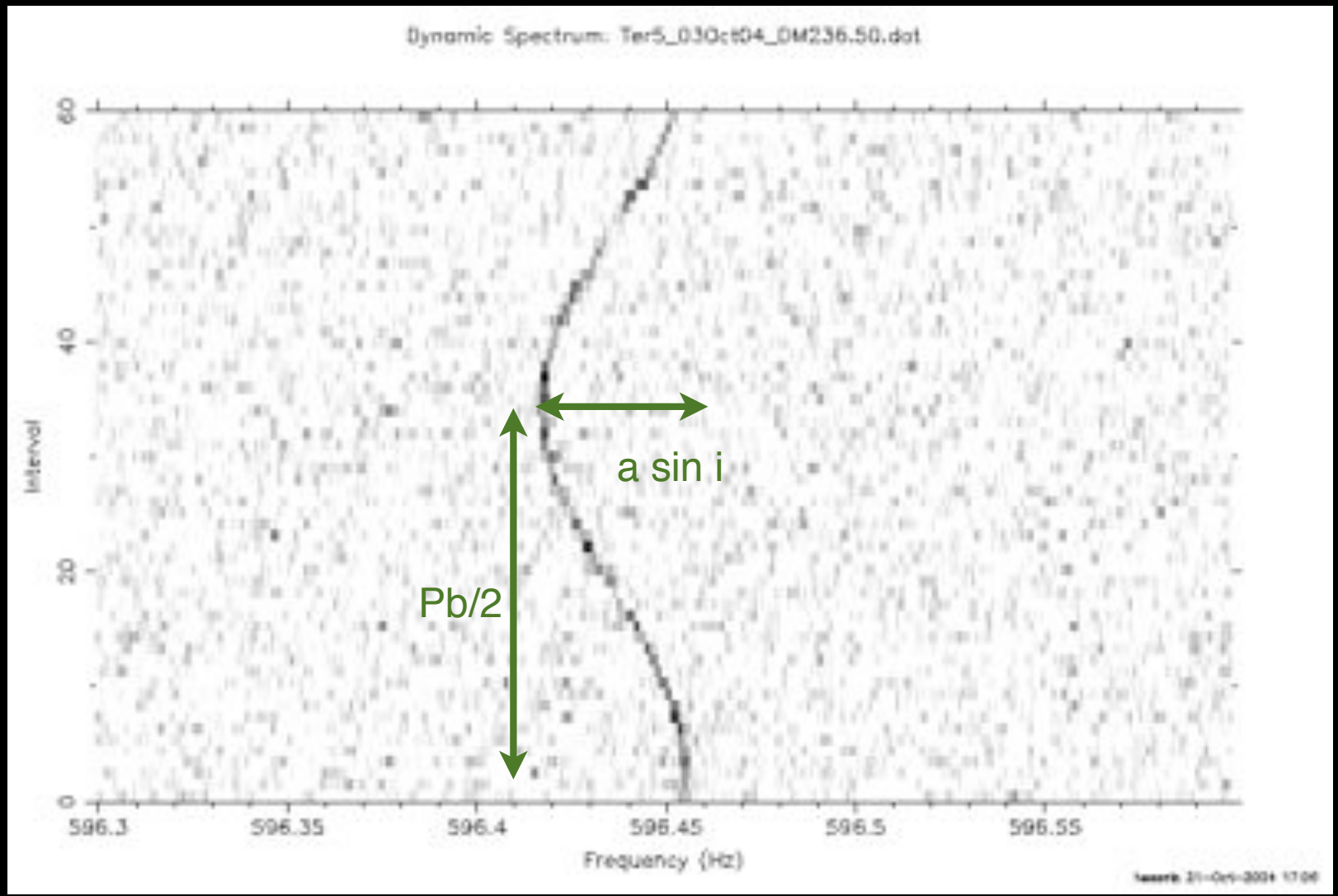


Coherent timing: use TOAs to unambiguously count every single rotation of pulsar over timescales of years.

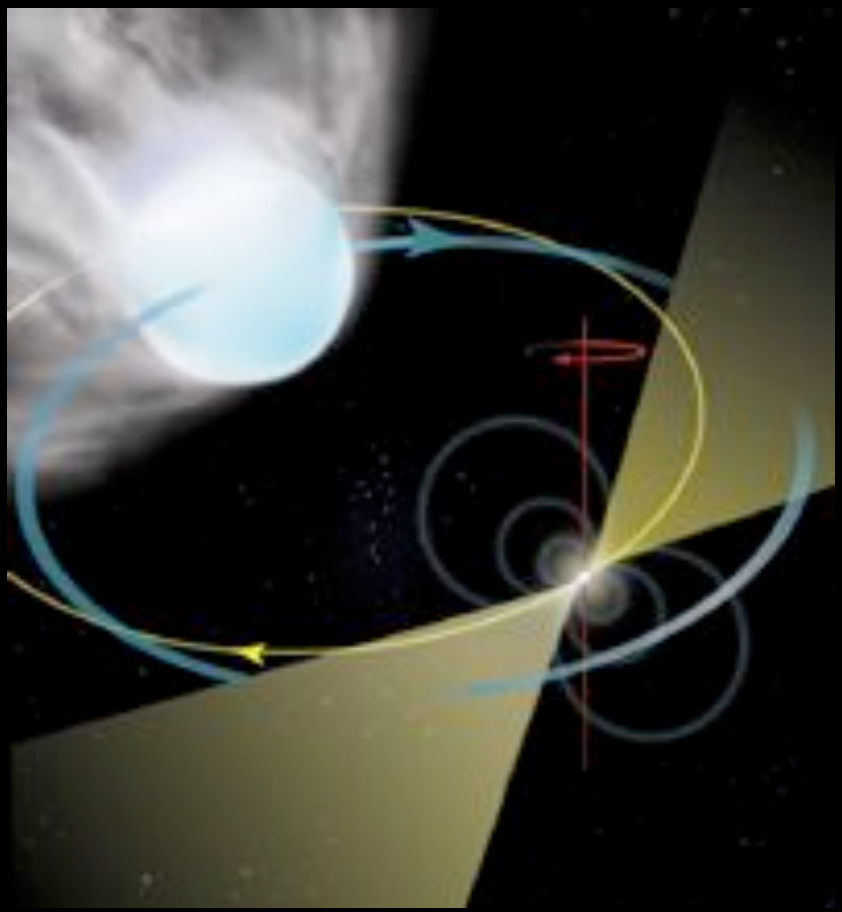
80% of MSPs are in Binaries



Pulsar Timing
Orbital Parameters



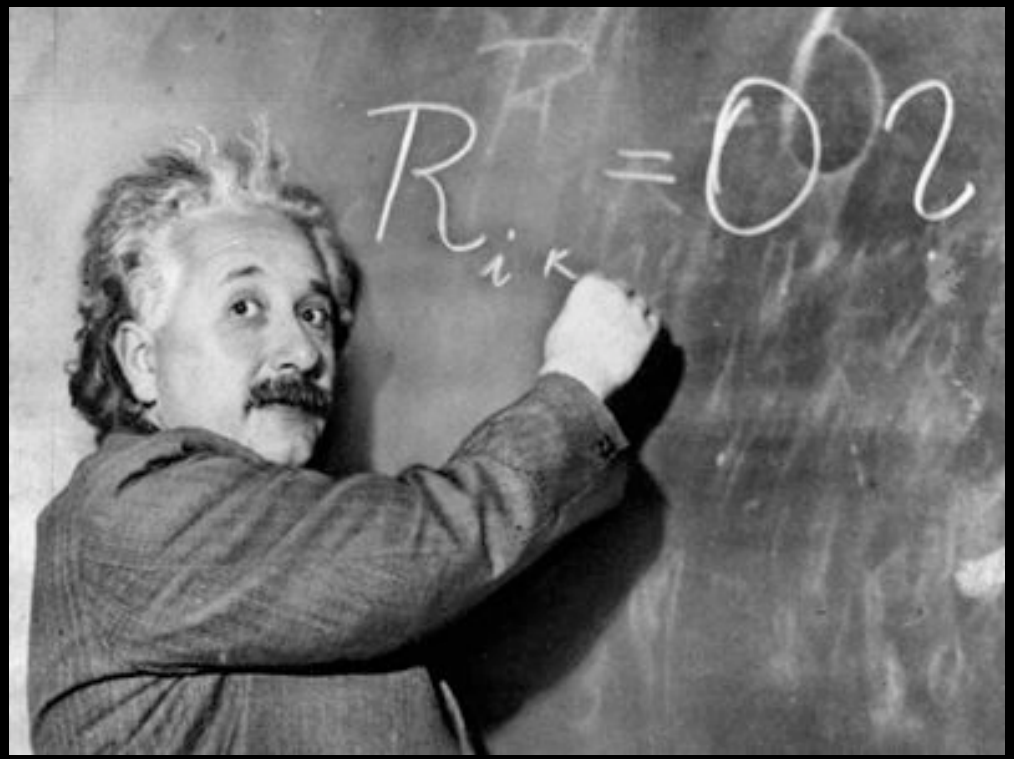
Pulsar Timing
Orbital Parameters



Keplerian Parameters

Projected semi-major axis (a sin i)
Time of periastron (To)
Longitude of periastron (w)
Orbital Period (Pb)
Eccentricity (e)

Pulsar Timing
Relativistic Orbital Parameters



Post Keplerian Effects

Periastron advance (wdot)
Orbital Decay (Pbdot)
Shapiro Delay (r,s)
Time dilation / grav. redshift (gamma)

Pulsar Timing Model

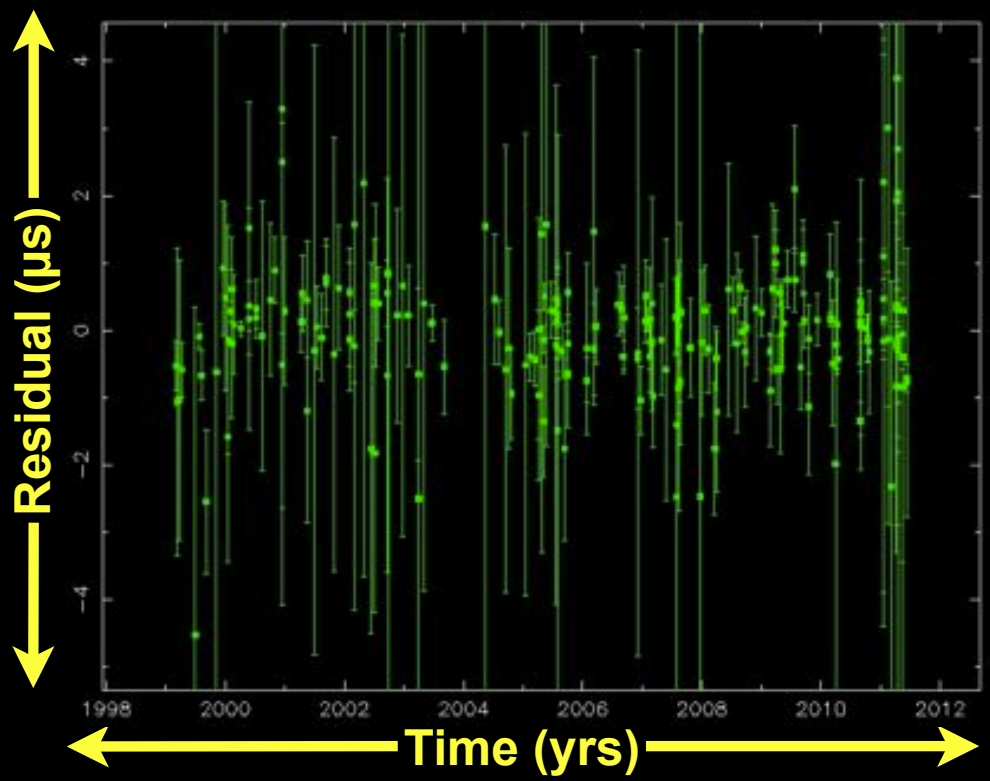
Input to PTAs

Basic Method:

Actual Pulse TOA

— Theoretical Model

= Timing Residual



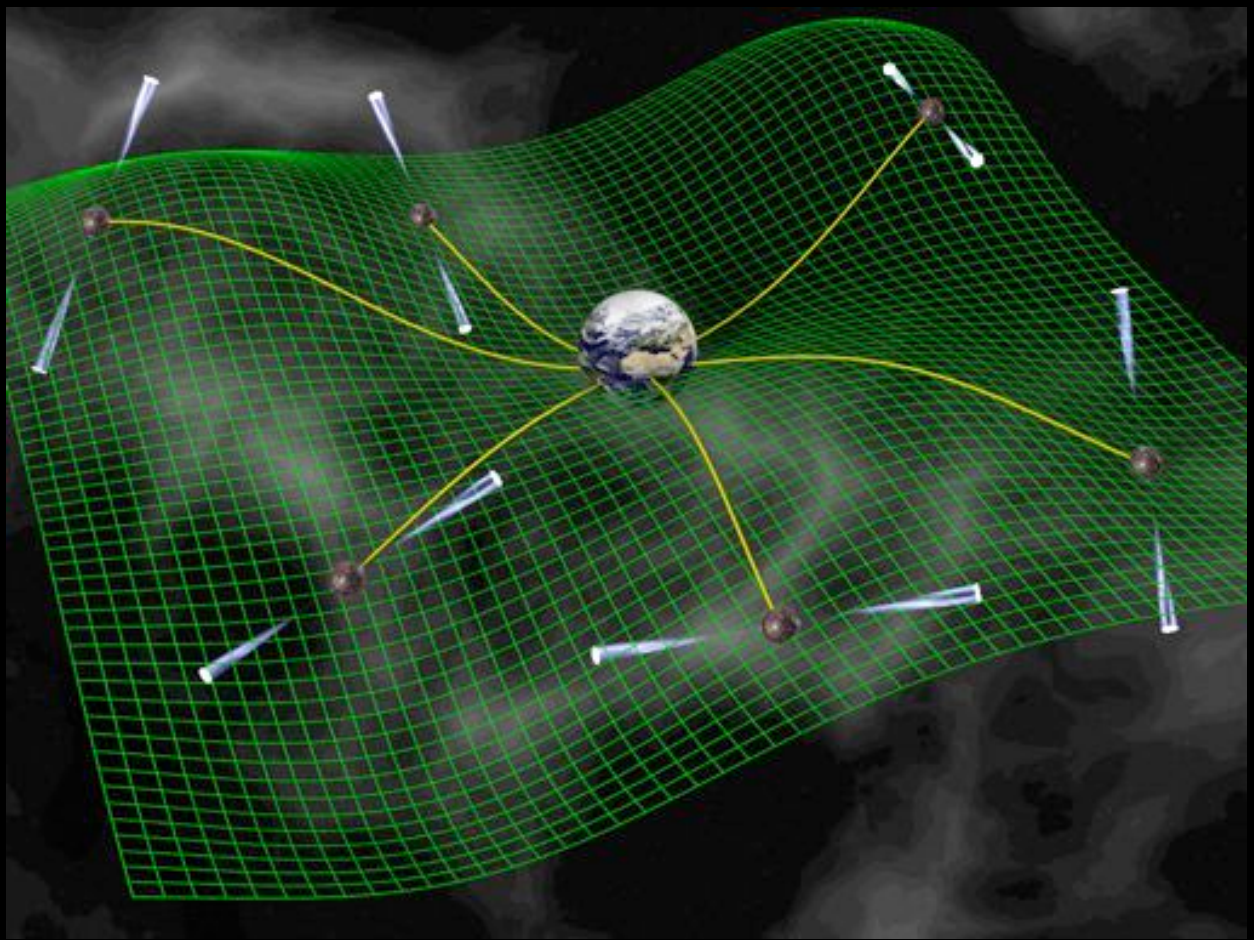
Courtesy Andrew Jameson (Swinburne)

$$T_{\rm th} = \nu t + \frac{1}{2}\dot{\nu} t^2 + D\frac{\int_0^d n_e dl}{f^2} - \frac{1}{c}(\vec{r}\cdot\hat{s}) + \frac{V_{\rm T}^2 t^2}{2cd} - \frac{(\vec{r}\times\hat{s})^2}{2cd} + \dots$$

Detecting GWs

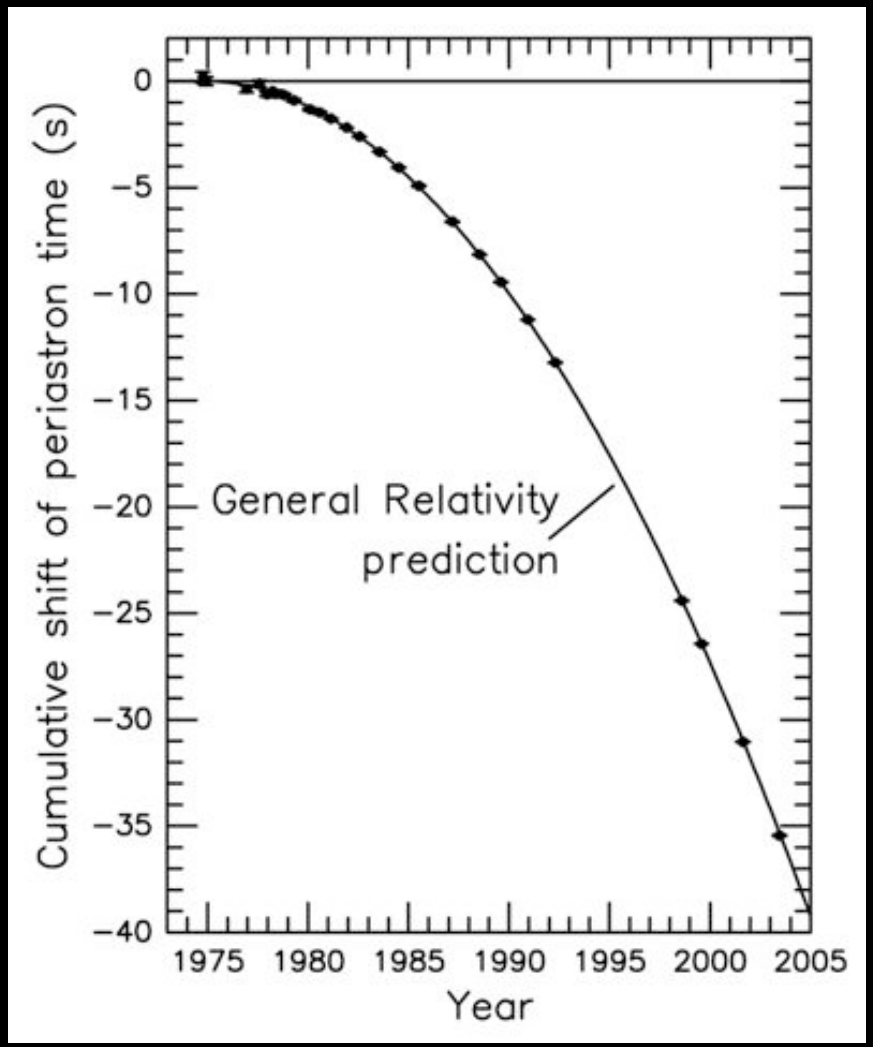
Pulsar Timing Array

PTAs are sensitive to individual periodic sources, bursts, and a GW background

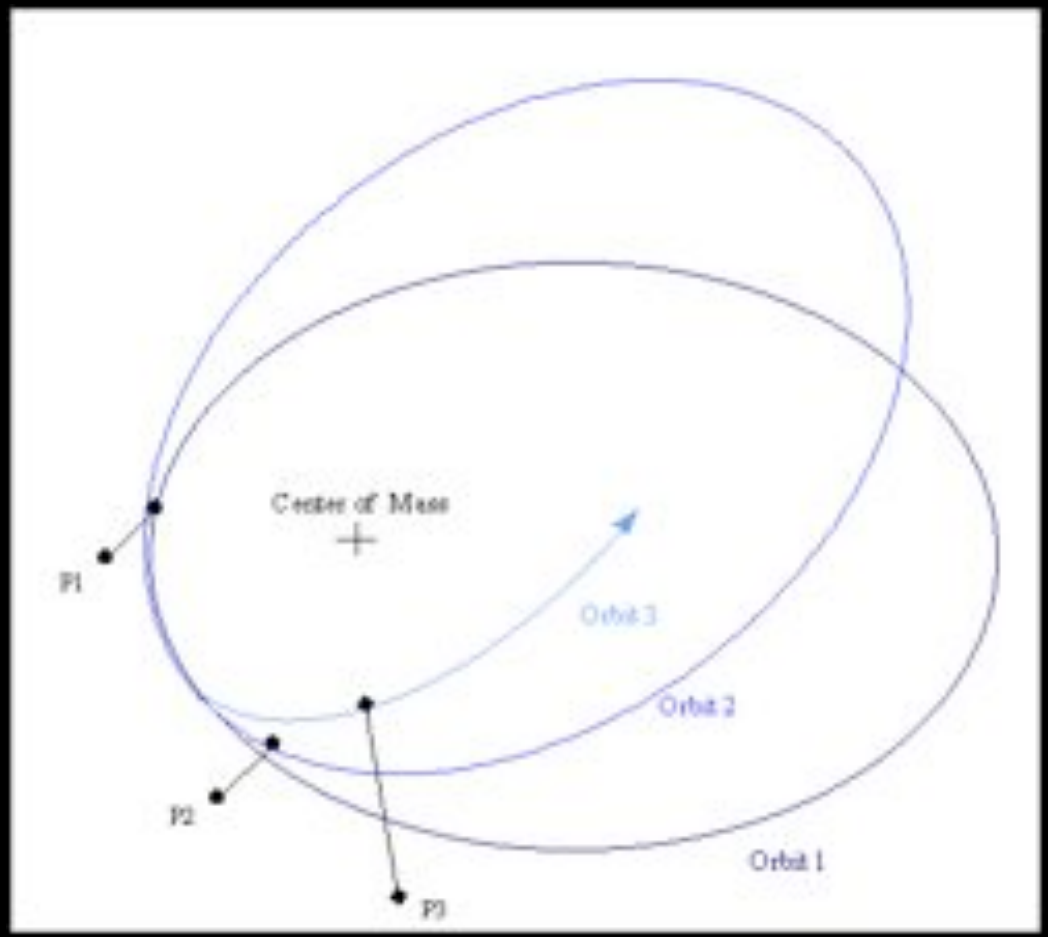


- Array of ~20 MSPs spread across the sky.
- Observe these roughly once a week.
- Sensitive to GWs with periods of months to years.
- e.g. detect the GW background due to supermassive BH binaries.

Hulse-Taylor Binary
Indirect GW detection



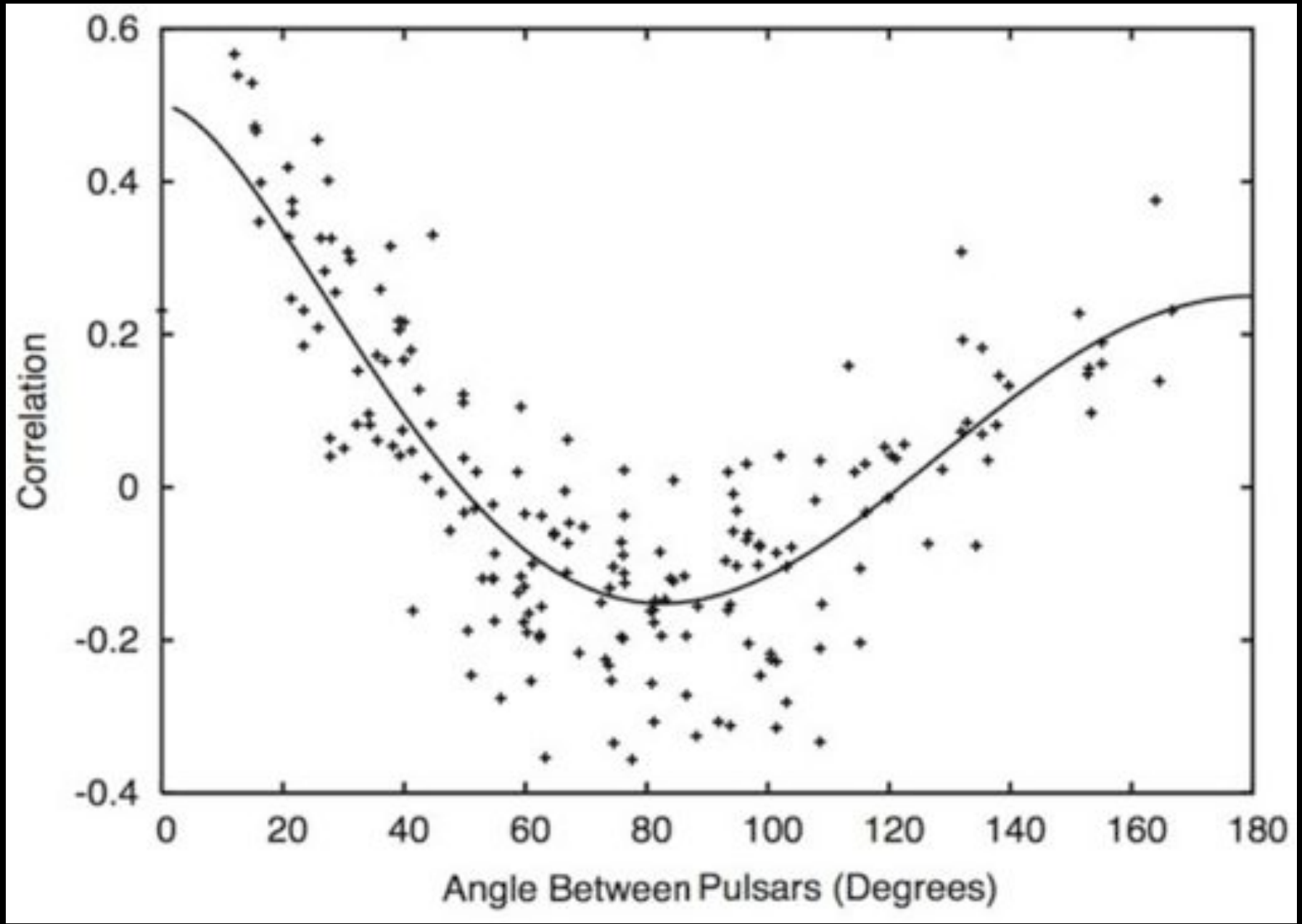
Taylor & Weisberg



Component masses from wdot and gamma,
Pbdot provided Nobel-worthy measurement

1993 Nobel Prize to Hulse & Taylor

Looking for Timing Correlations



Graph courtesy of Daniel Yardley (USyd)

Hellings & Downs, 1983

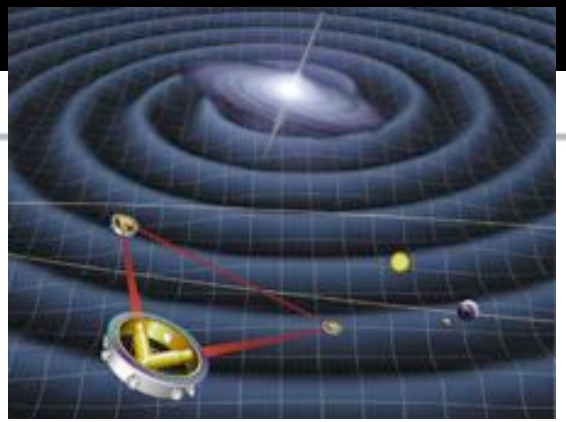
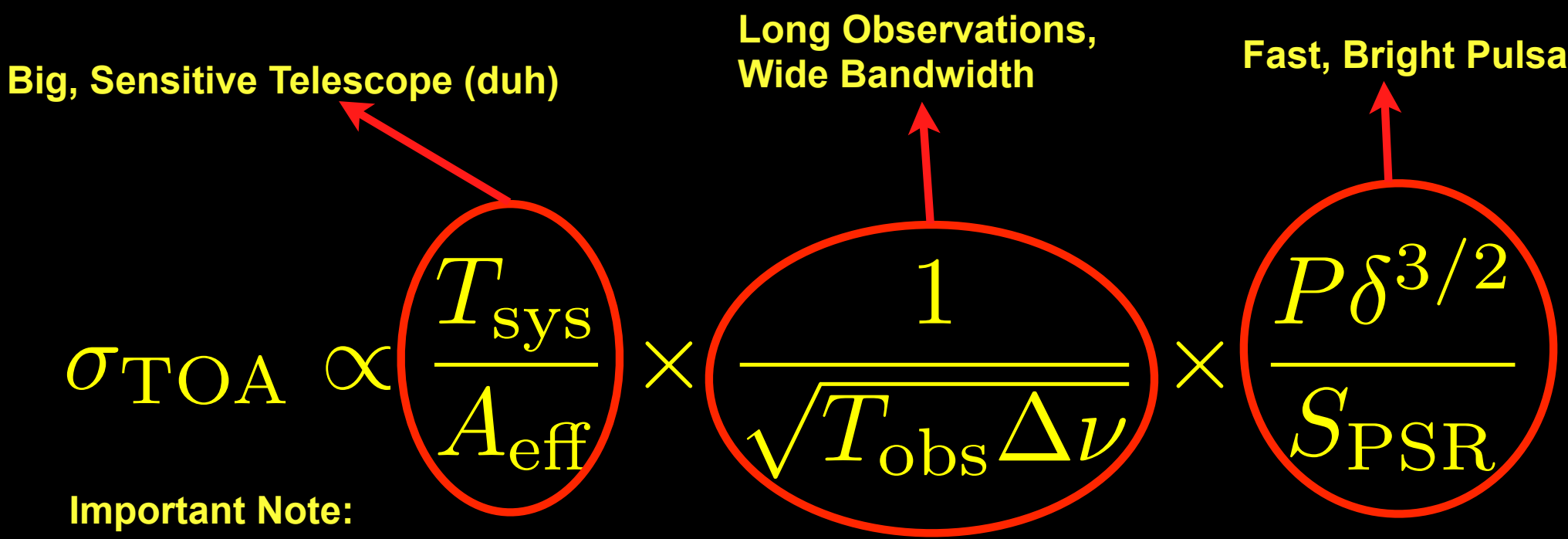


Figure courtesy George Hobbs (ATNF)

TOA Precision



Important Note:

$$S_{\mathrm{PSR}} \propto \nu^{\alpha}$$

with $\alpha \approx -1.6 < 0$

Timing Precision

- Dominated by TOA precision (σ_{TOA})

- However, increasing corruptions from:
- ISM
- Instrumental stability
- Intrinsic Pulsar Stability
- ...

Get ~100ns residuals on 20 pulsars

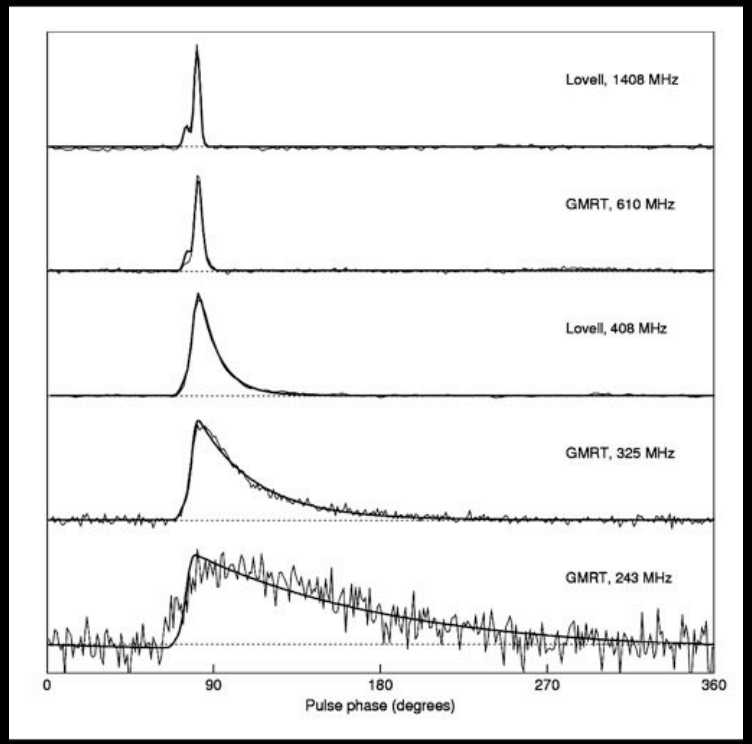
Propagation effects in the ionized interstellar medium

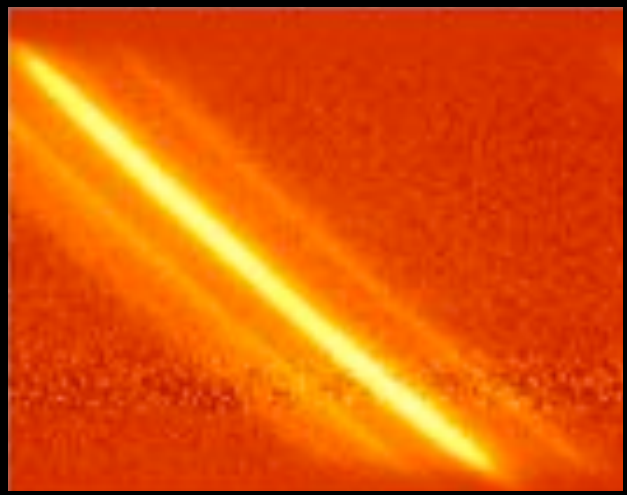
$$I(t) = g_r g_d S(t) * h_{\mathrm{DM}}(t) * h_d(t) * h_{\mathrm{Rx}}(t) + N(t)$$

Scattering: multi-path propagation

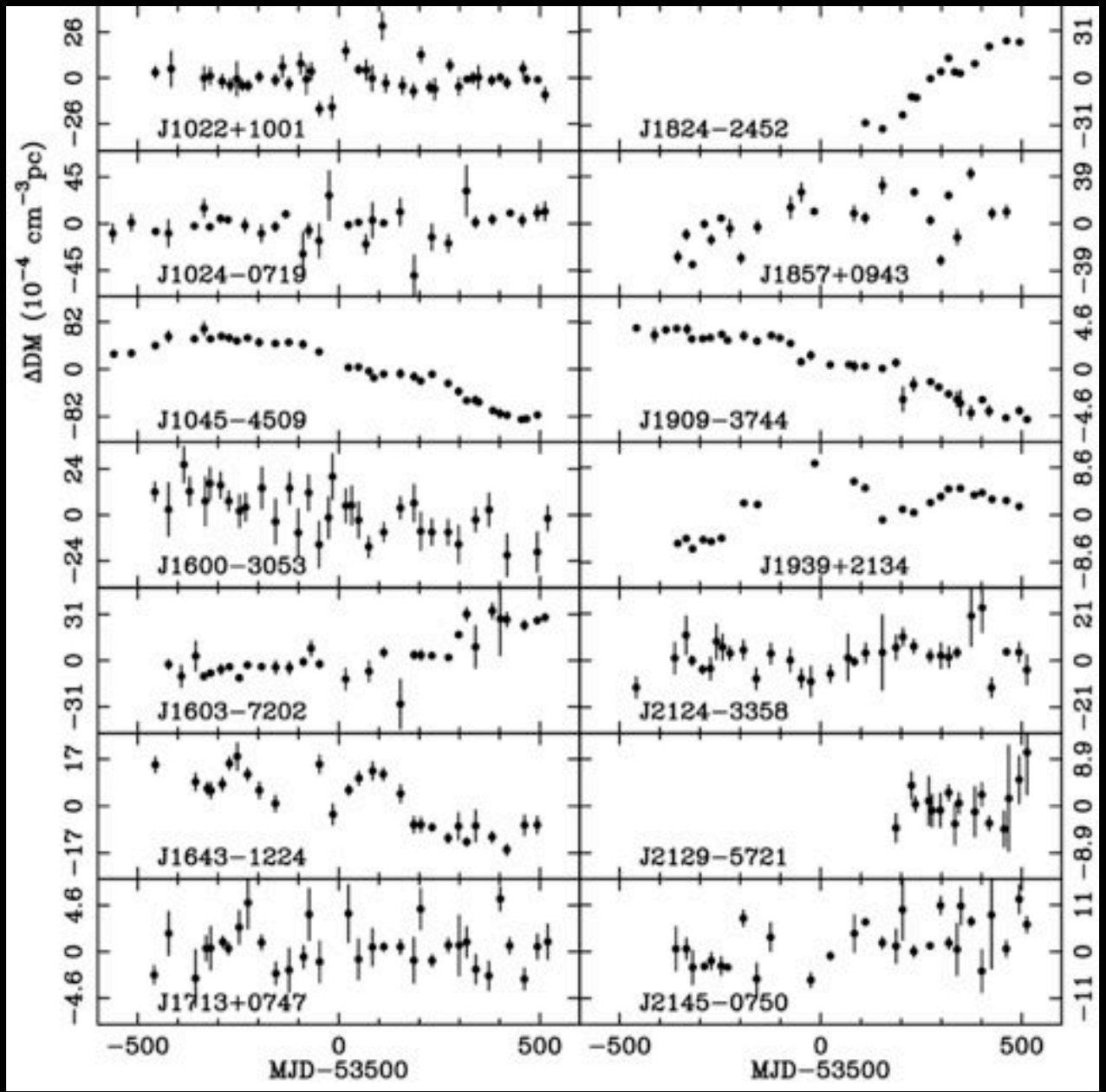
Dispersion: freq. dependent arrival time

Scintillation: const./dest. interference



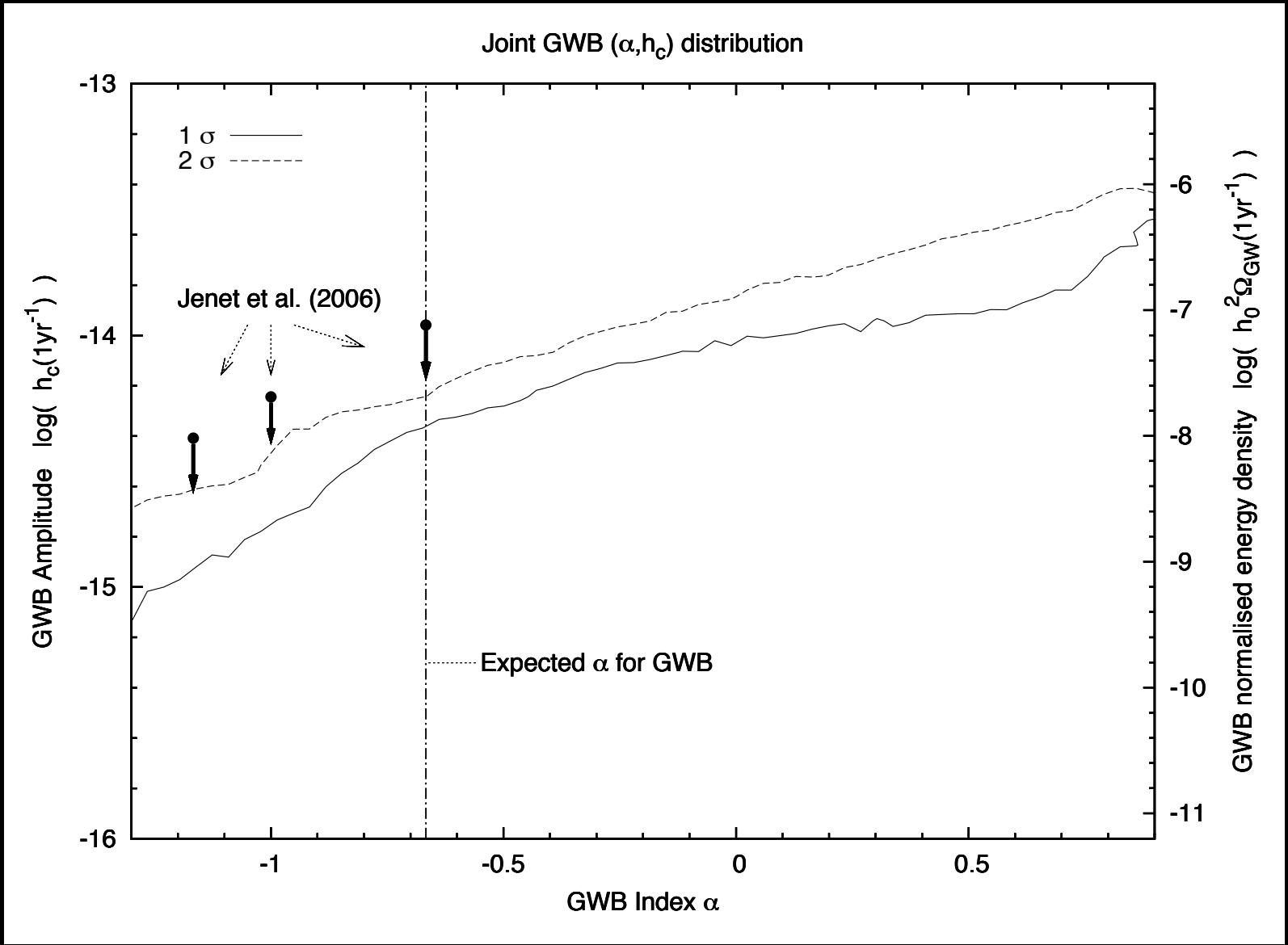


DM Variations



You et al. (MNRAS, 2007)

EPTA GWB Limit



van Haasteren et al. 2011

PTA Consortia

Pulsar Timing Array Consortia

NANOGrav

EPTA

PPTA

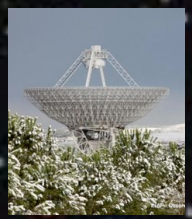
Arecibo

Westerbork

Effelsberg

Parkes

Nançay



Sardinia

Green Bank

Lovell

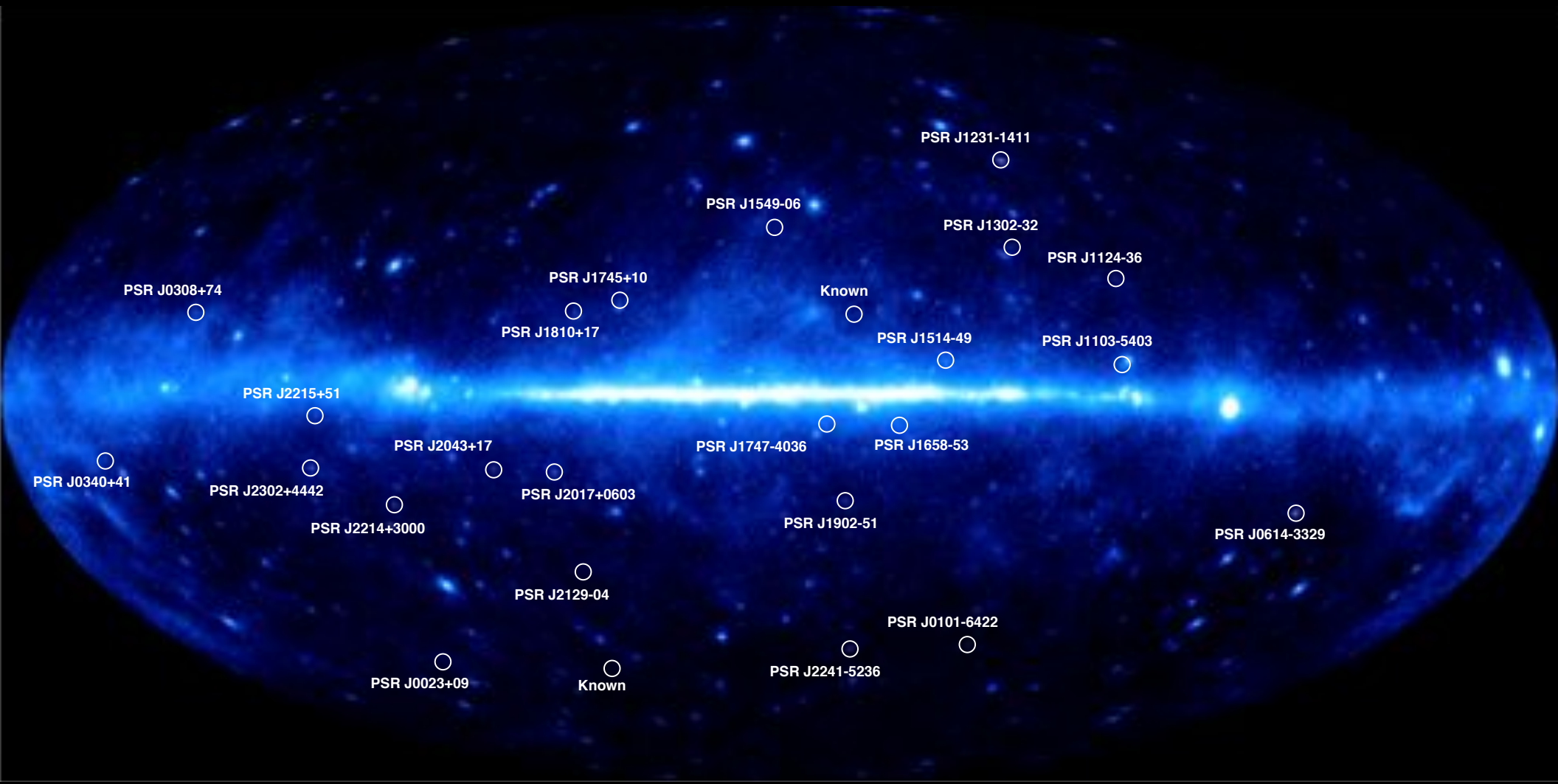
International Pulsar Timing Array

Figure courtesy of Brian Burt, Franklin & Marshall

See www.ipta4gw.org

Future Prospects

Close to 40 new MSPs Found via Fermi Searches



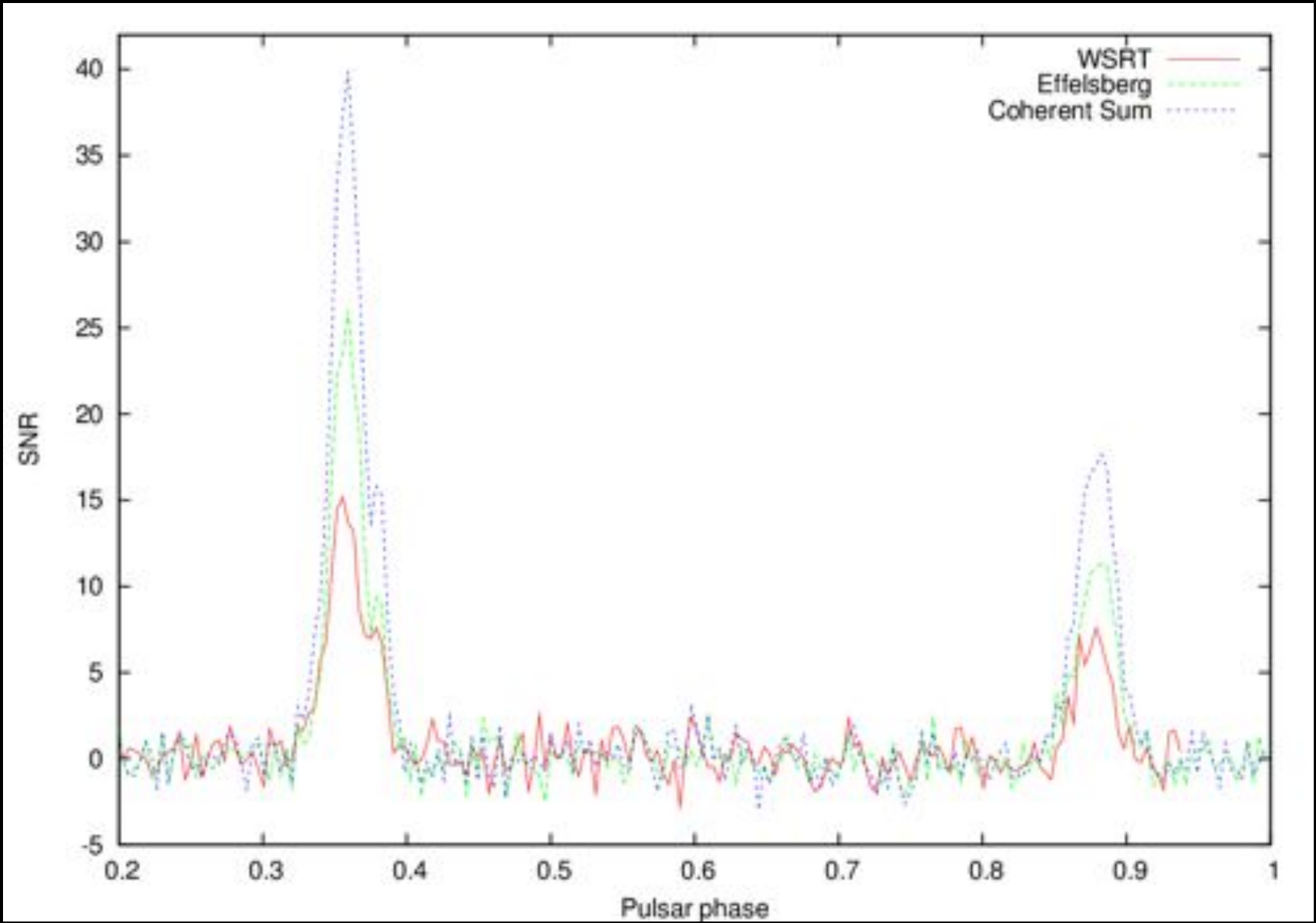
Note that in the last 30 years only 60 MSPs have been found in the Galactic Plane.

Large European Array for Pulsars (LEAP)

- Coherent combination of 5 major European telescopes (at 20cm)

➡ 4% SKA

B1937+21 with (proto) LEAP

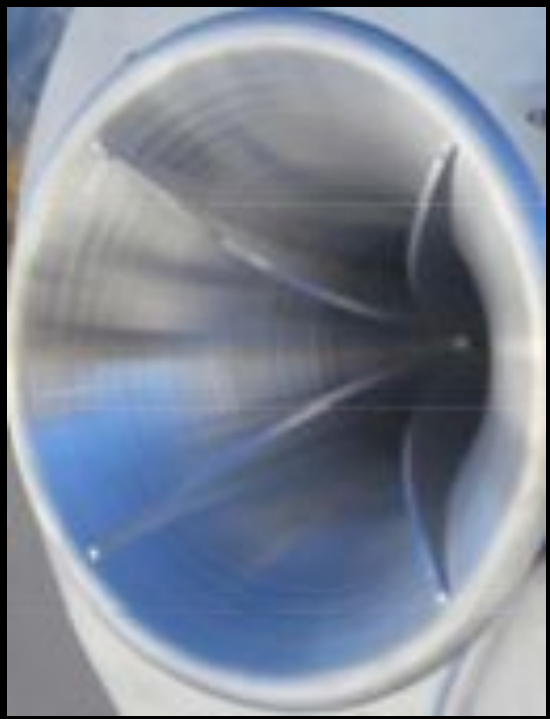


Smits et al.

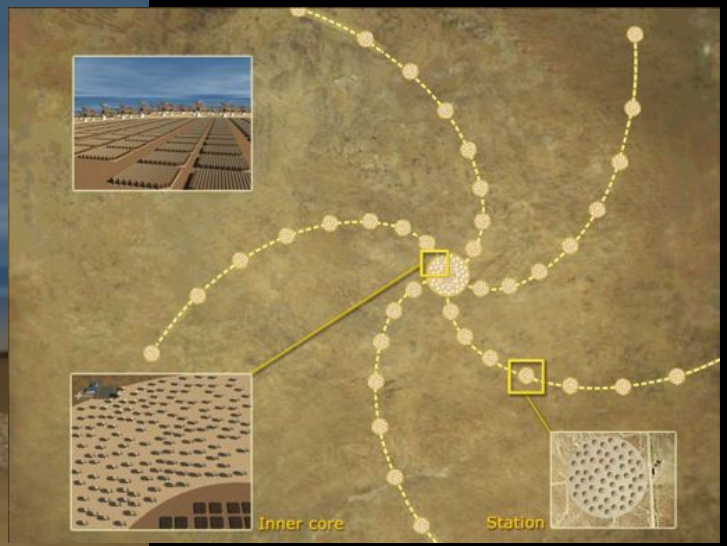

LOFAR

Effelsberg UBB Receiver

Ultra-Broad-Band receiver
ERC Grant to Paulo Freire
600MHz – 3GHz coherent dedispersion using GPUs and ROACHes
Feed design: S. Weinreb (JPL)



Square Kilometer Array (SKA)



GWs with Pulsars one of two key projects for Phase 1