Masses of Radio Pulsars

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UBC
SQM Meeting
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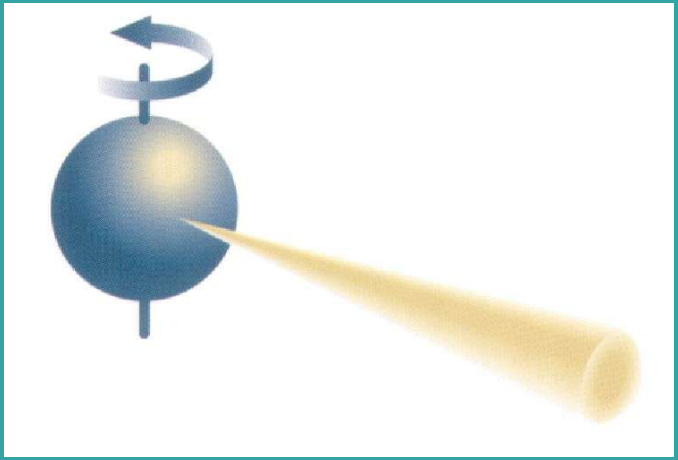
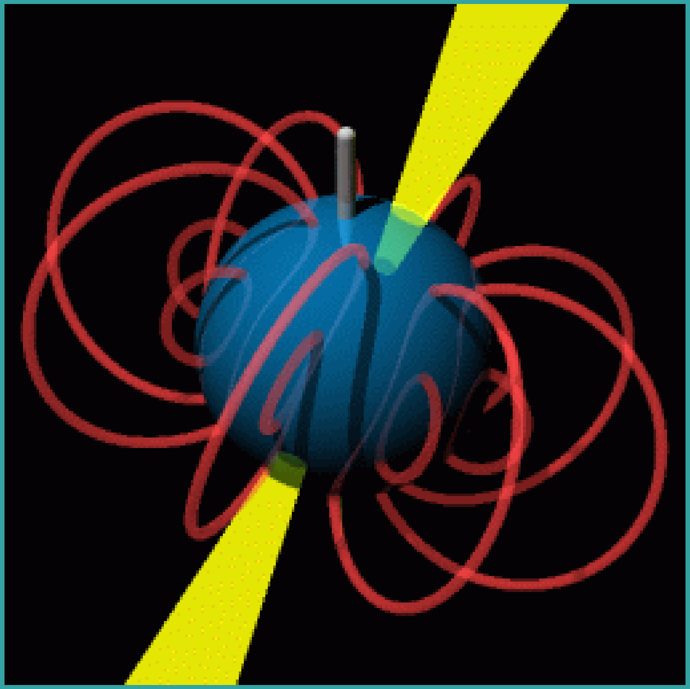
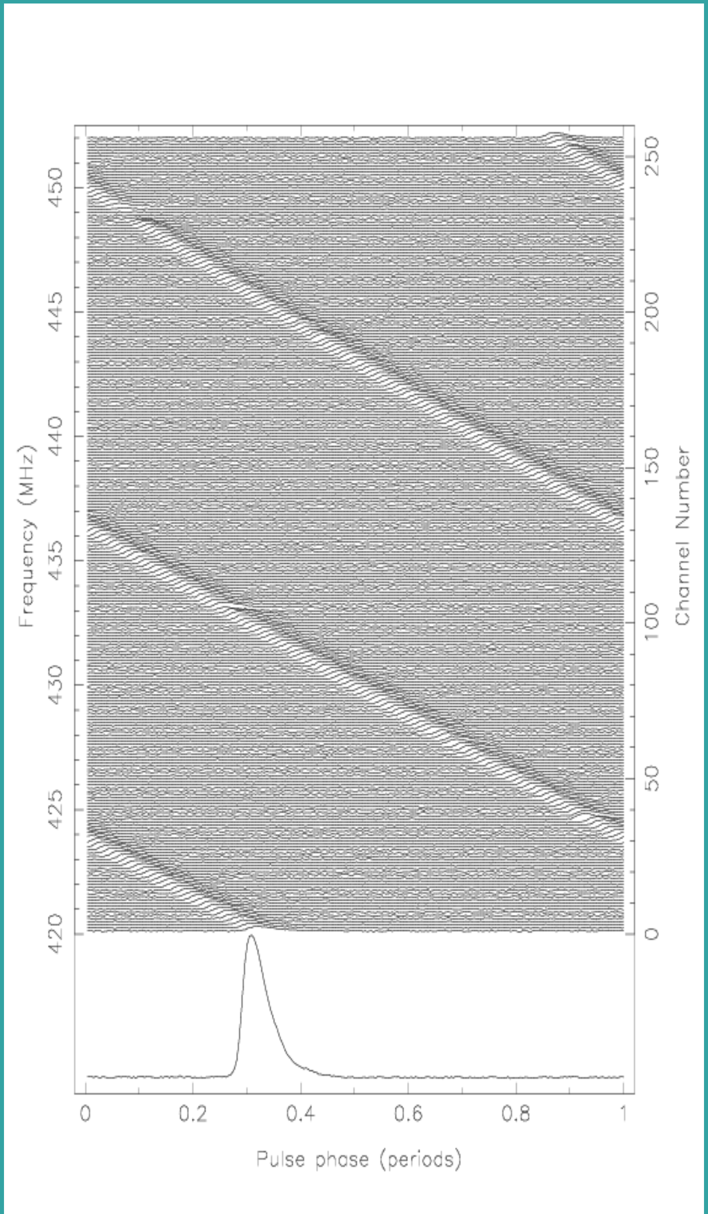


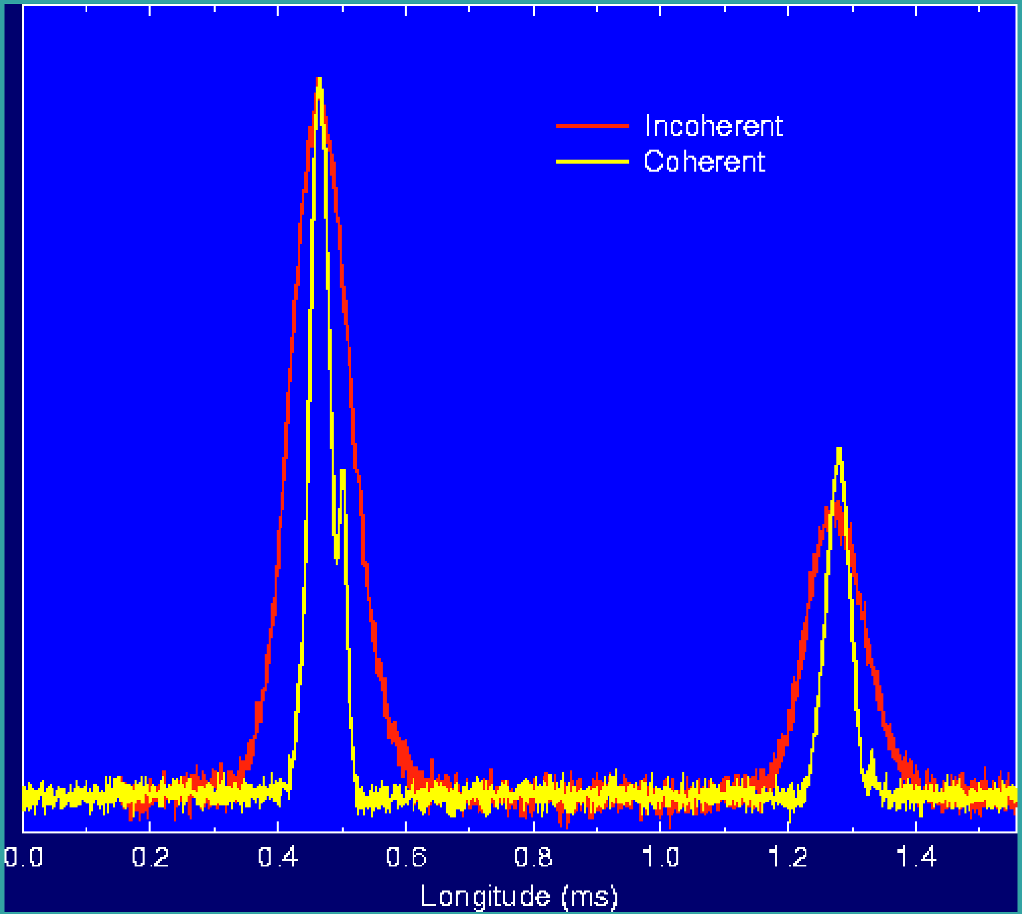
Pulsars are identified with rotating, magentized neutron stars.
Low fluxes mean large radio telescopes are needed to detect them.



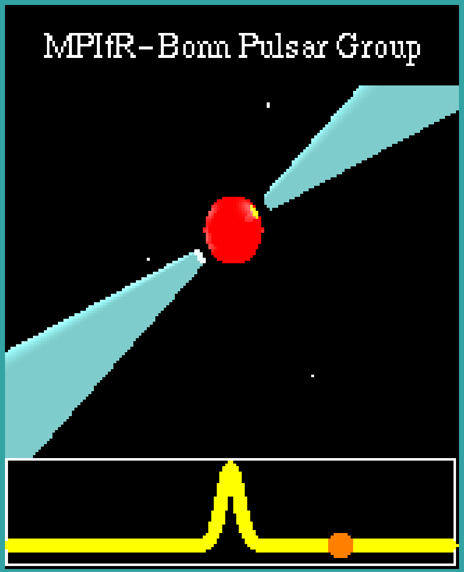
Dispersion and its Removal



Filterbank: residual smearing in channels

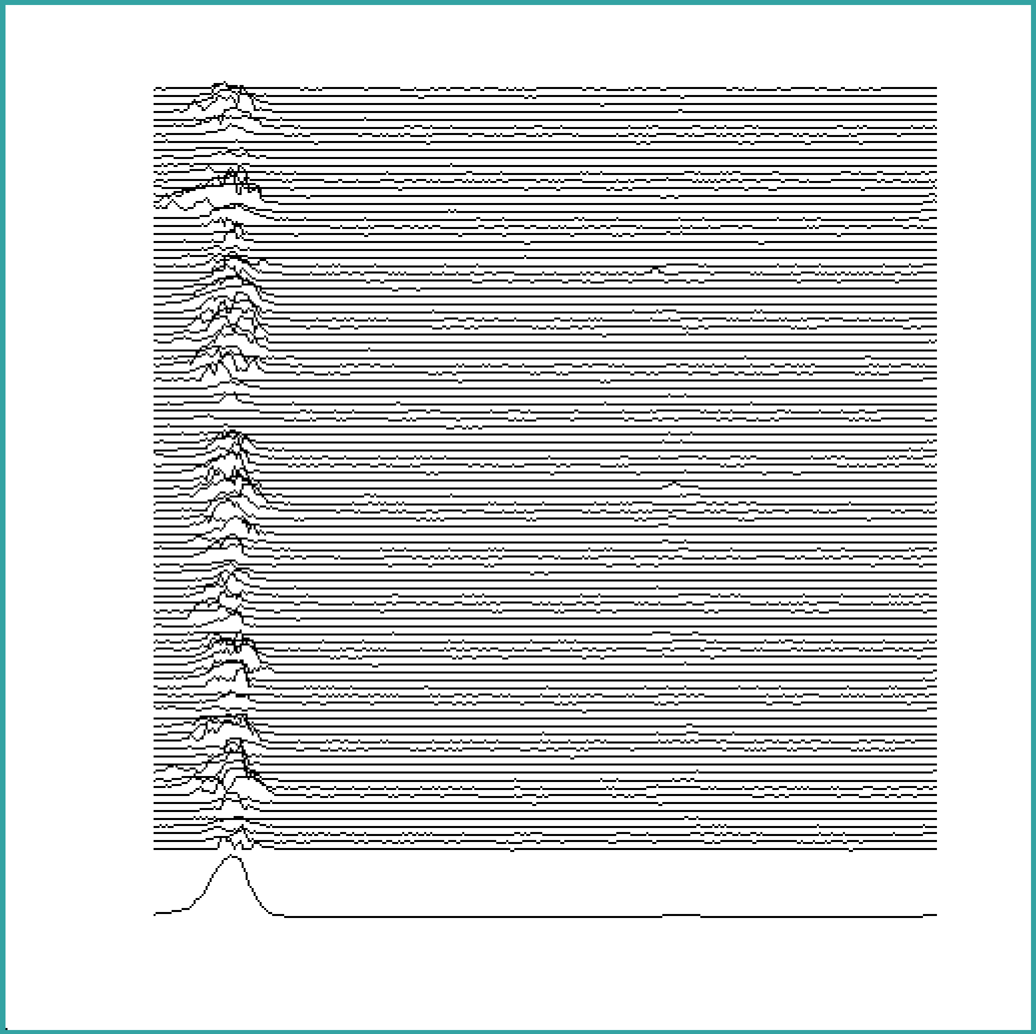


Coherent Dedispersion: computationally intensive, but sharper profiles ⇒ better timing



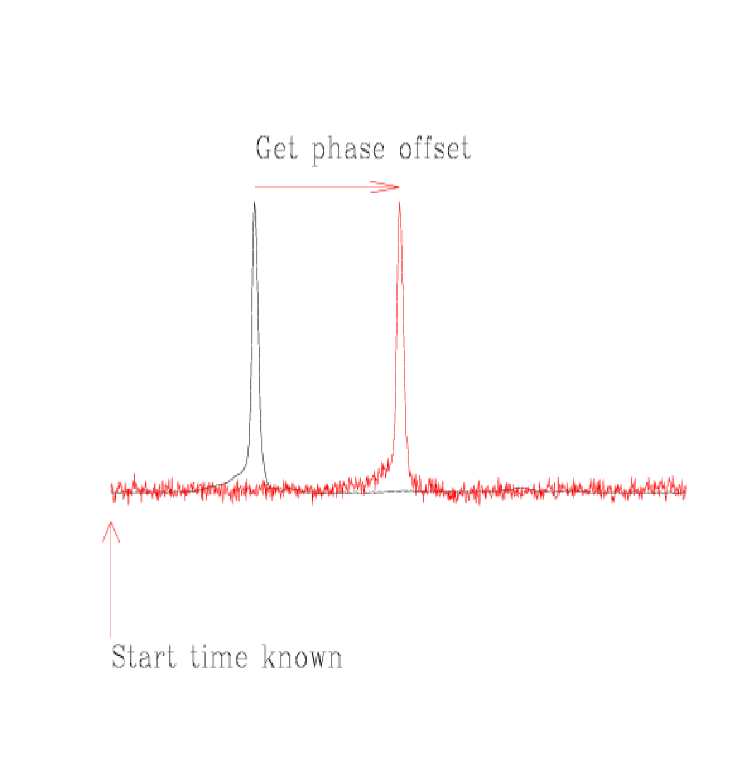
Lighthouse model

Pulse-to-pulse variations



Integrated profile: stability when hundreds to thousands of pulses are added.

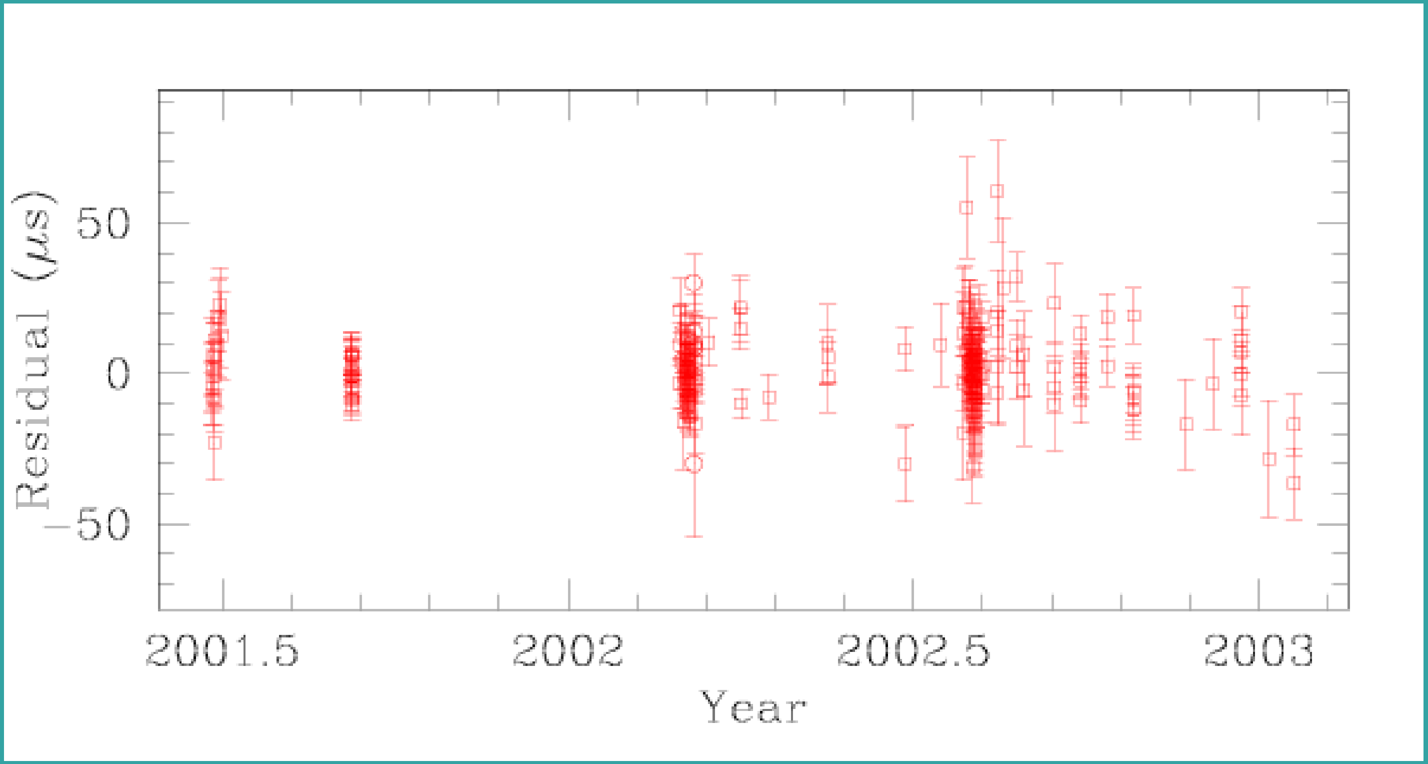
Cross-correlation with standard profile: Time-of-Arrival (TOA)



PSR B1534+12: between
23 Aug. 1990 20:56:17.030
and
9 March 2006 09:00:16.722
there were exactly
12 939 121 017 pulses.

High-precision timing: transform to Solar System Barycentre;
fit spin and astrometric parameters, and binary parameters
if needed.

Timing Residuals: Actual TOAs – Predicted



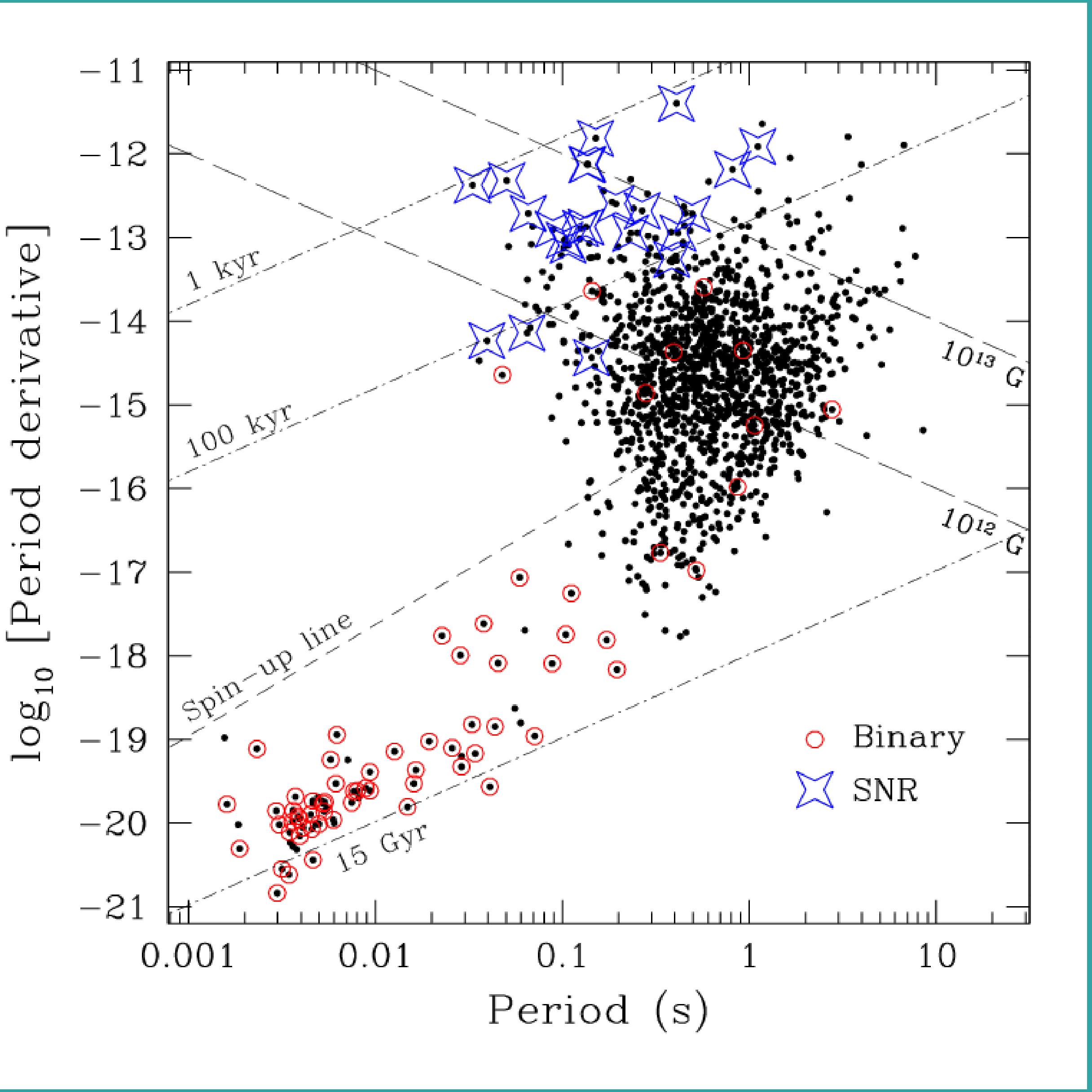
M13C: Ransom et al. in prep

Ideally: no systematics in residuals.

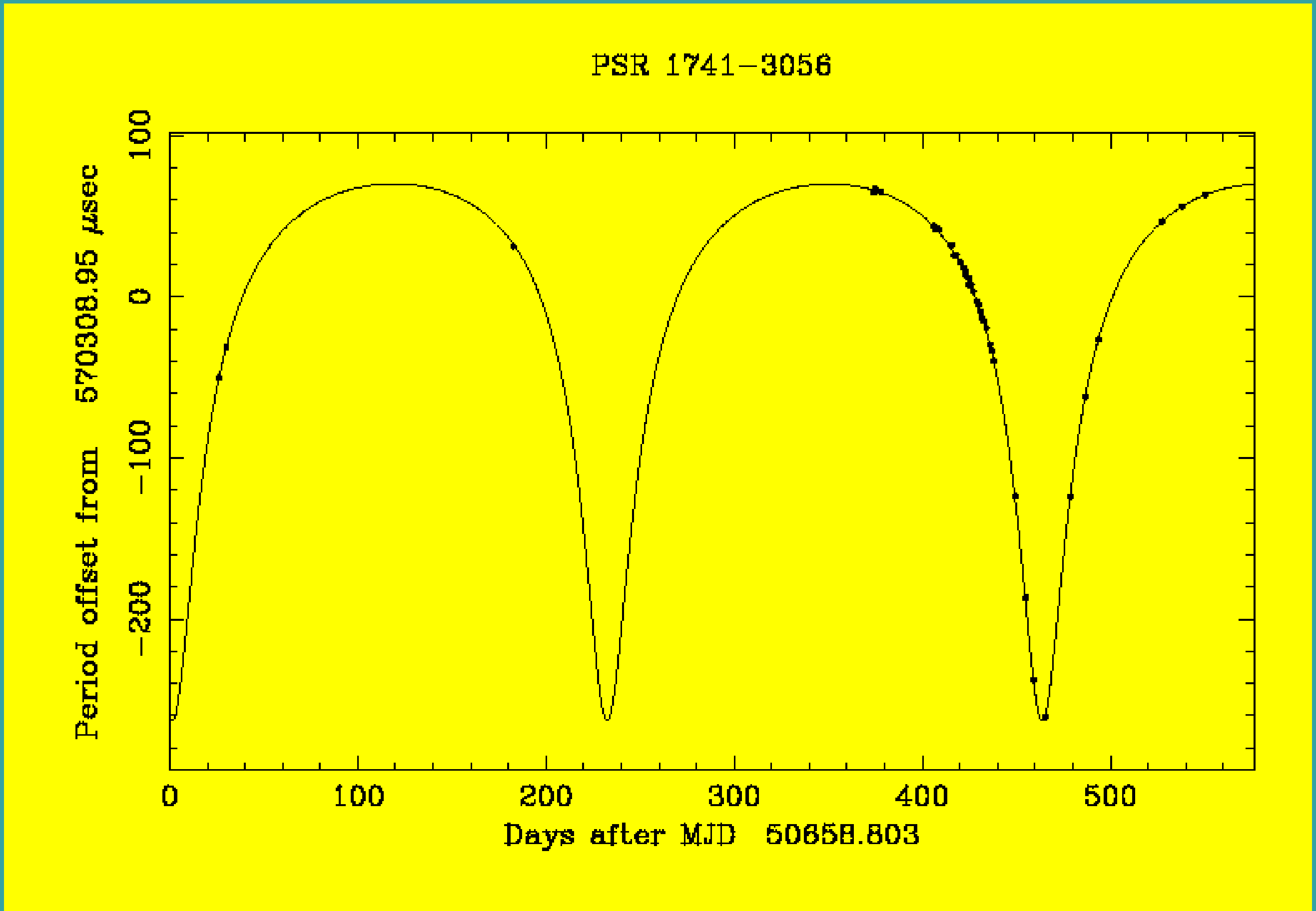
The Pulsar Population

$$\tau = \frac{P}{2\dot{P}}$$

$$B = 3.2 \times 10^{19} \sqrt{P\dot{P}}\, G$$



Binary Pulsars



Doppler shift in period is quickly obvious. All systems: fit basic Keplerian parameters: P_b, ecc, asini = x, ω and T_0.

The 5 Keplerian parameters leave the two masses and the orbital inclination angle i unknown.
These are related by the mass function:

$$\left(\frac{2\pi}{P_b}\right)^2 \frac{x^3}{T_O} = \frac{(m_2 \sin i)^3}{(m_1 + m_2)^2}$$

... but there are still two unknowns.

So measuring masses is difficult!

It's only possible when we can measure "post-Keplerian" (PK) parameters:
advance of periastron, time dilation/redshift, orbital period decay and/or Shapiro delay.

Assuming general relativity (GR) is the correct theory of gravity, we can get the masses from the PK parameters:

$$\dot{\omega}=3\left(\frac{P_b}{2\pi}\right)^{-5/3}(T_O M)^{2/3}(1-e^2)^{-1}$$

$$\gamma=e\left(\frac{P_b}{2\pi}\right)^{1/3}T_O^{2/3}M^{-4/3}m_2(m_1+2m_2)$$

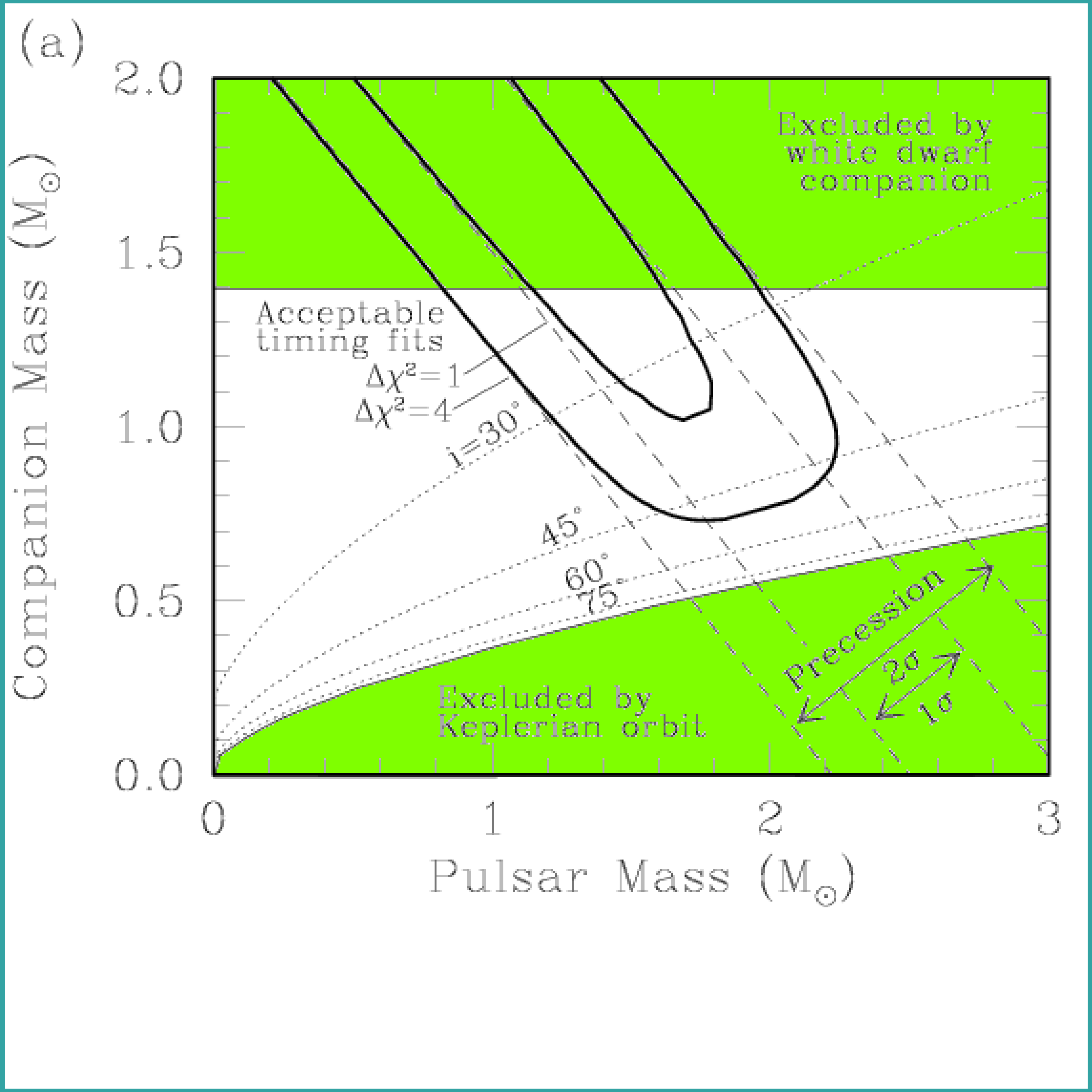
$$\dot{P}_b=\frac{-192\pi}{5}\left(\frac{P_b}{2\pi}\right)^{-5/3}\left(1+\frac{73}{24}e^2+\frac{37}{96}e^4\right)(1-e^2)^{-7/2}T_O^{5/3}m_1 m_2 M^{-1/3}$$

$$r=T_O m_2$$

$$s=x\left(\frac{P_b}{2\pi}\right)^{-2/3}T_O^{-1/3}M^{2/3}m2^{-1}$$

$$T_O=4.925490947\,\mu s$$

The mass constraints are easily understood via a mass-mass diagram.



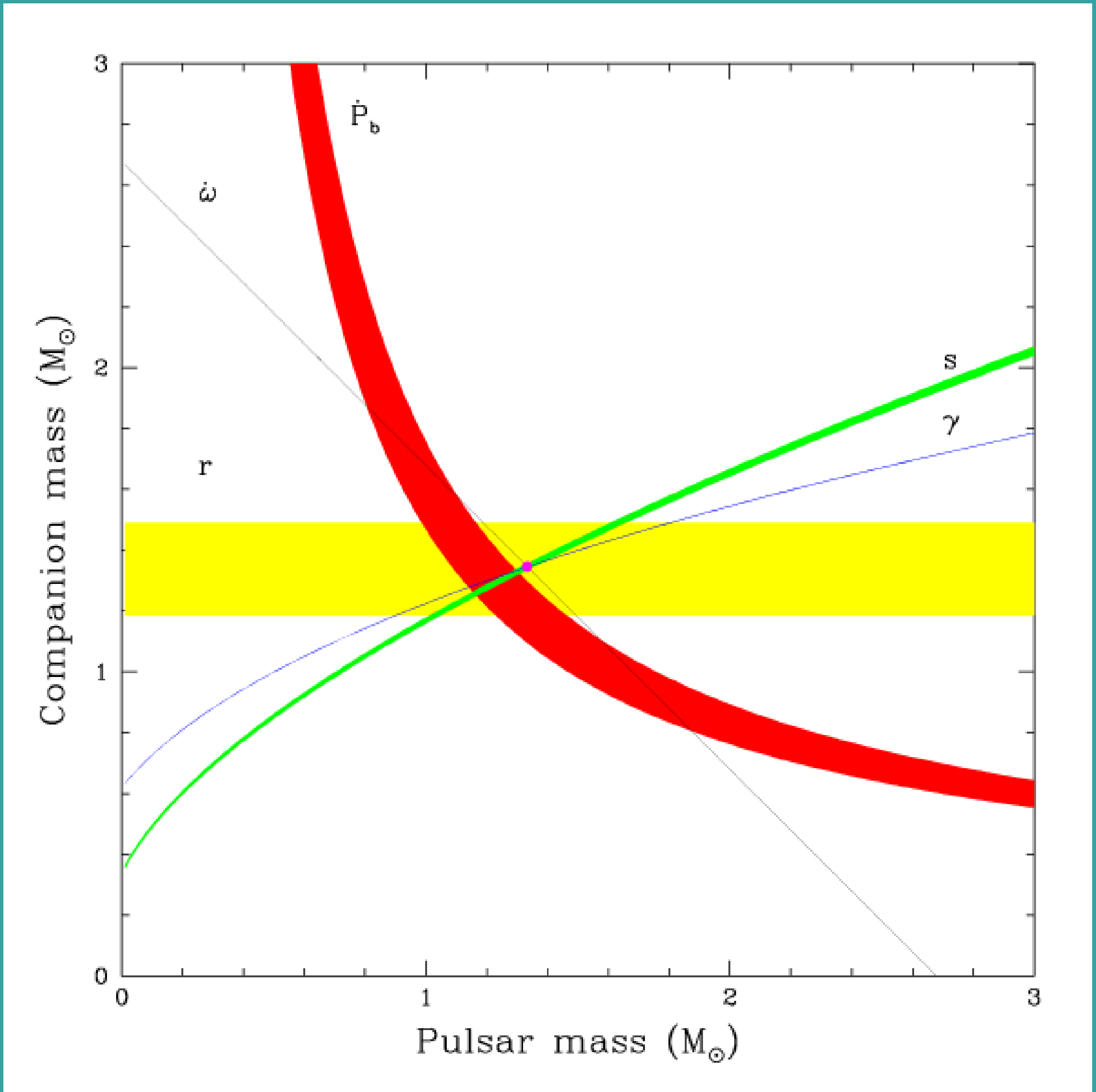
Splaver et al., ApJ 581, 509 (2002)

J0621+1002: advance of periastron measured; limit on Shapiro delay

Pulsar mass:

$1.70^{+0.32}_{-0.29}\ M_{solar}$

More PK params in double-NS binaries



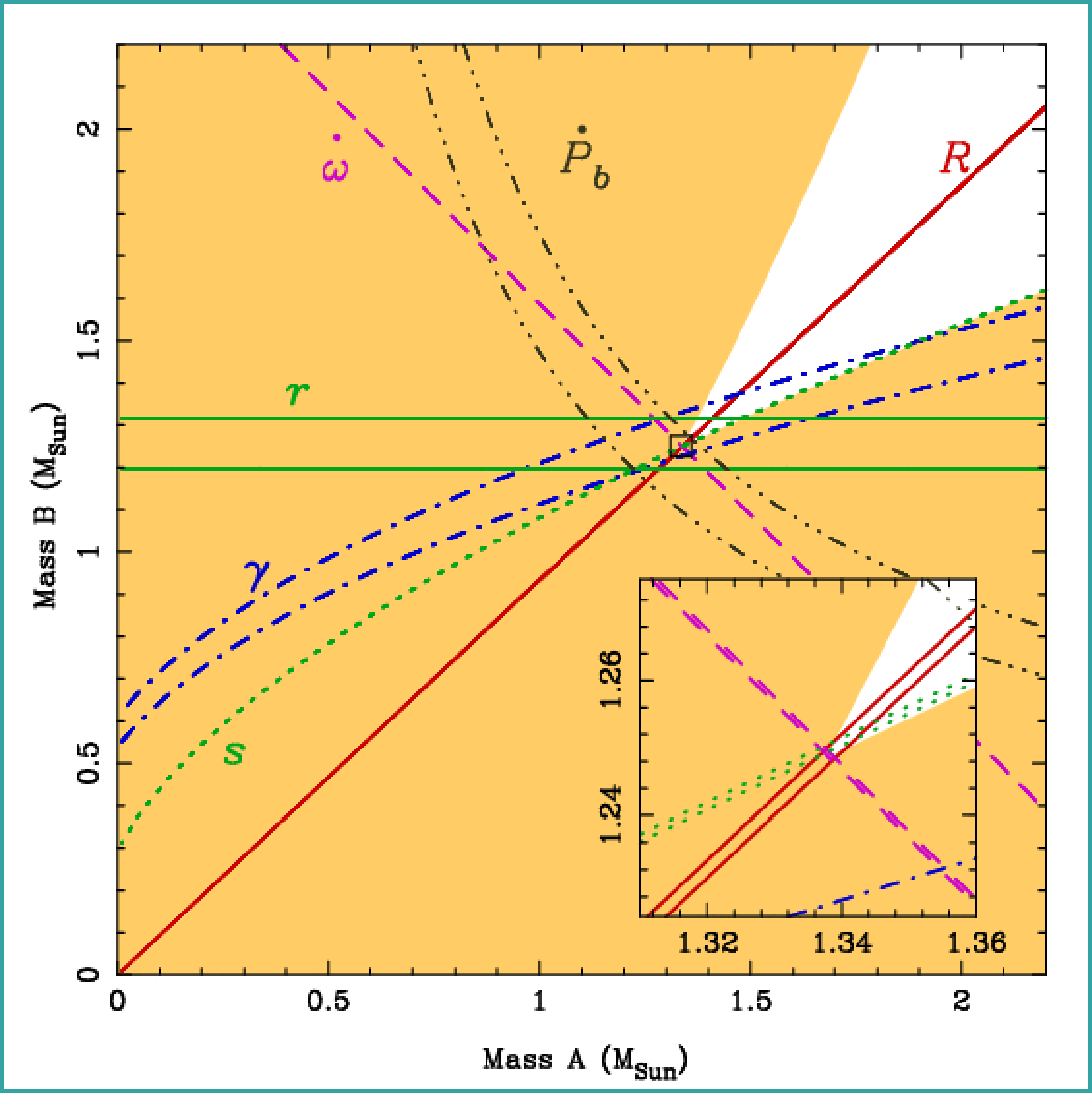
PSR B1534+12
(Stairs et al, unpublished)

5 PK parameters including Shapiro delay ⇒

masses precisely measured

PLUS self-consistency tests of GR or other theories of strong-field gravity.

The double pulsar J0737-3039

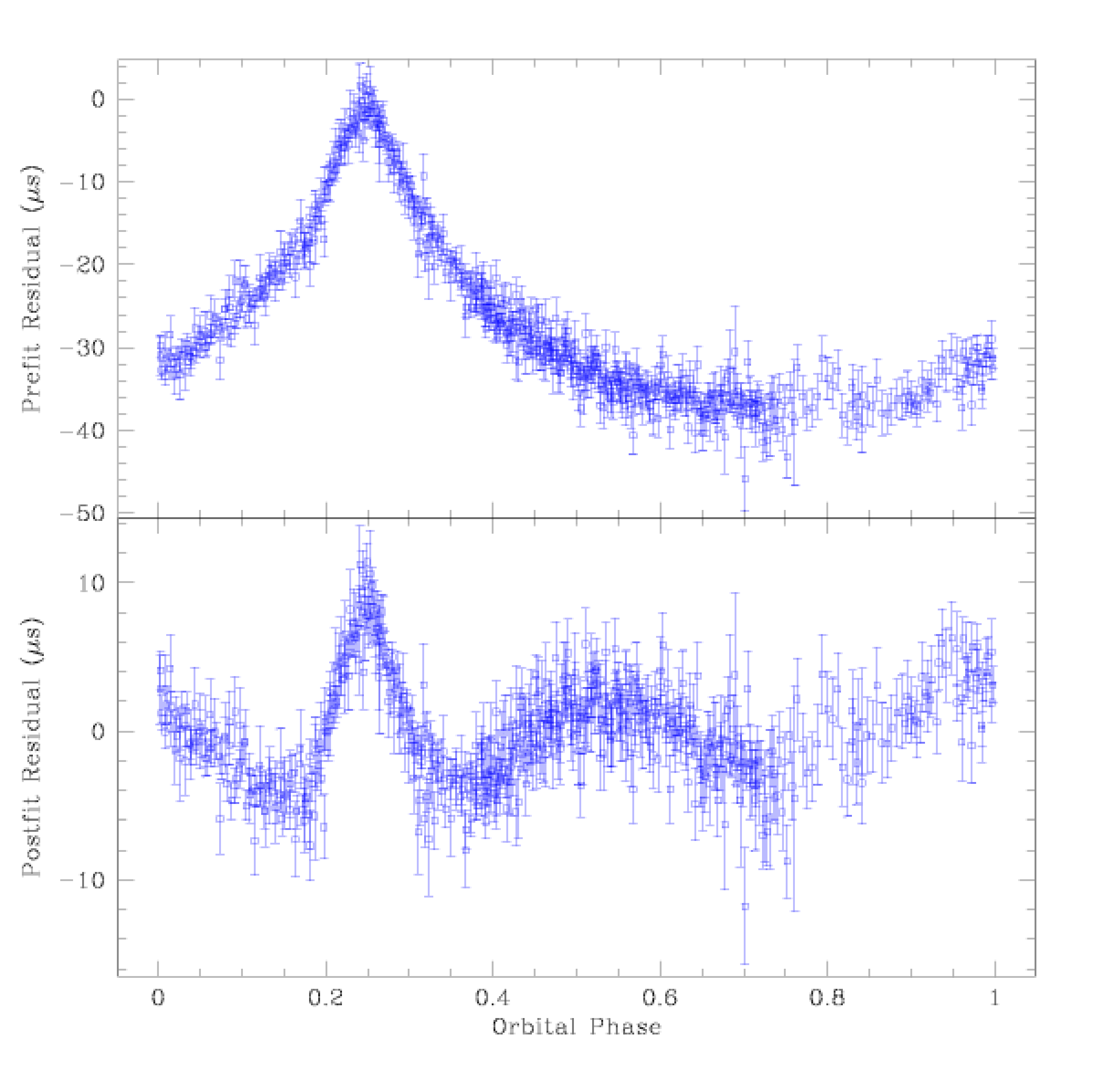


5 PK params plus the mass ratio!

Kramer et al., astro-ph/0503386

Stay tuned for an update...

Shapiro Delay

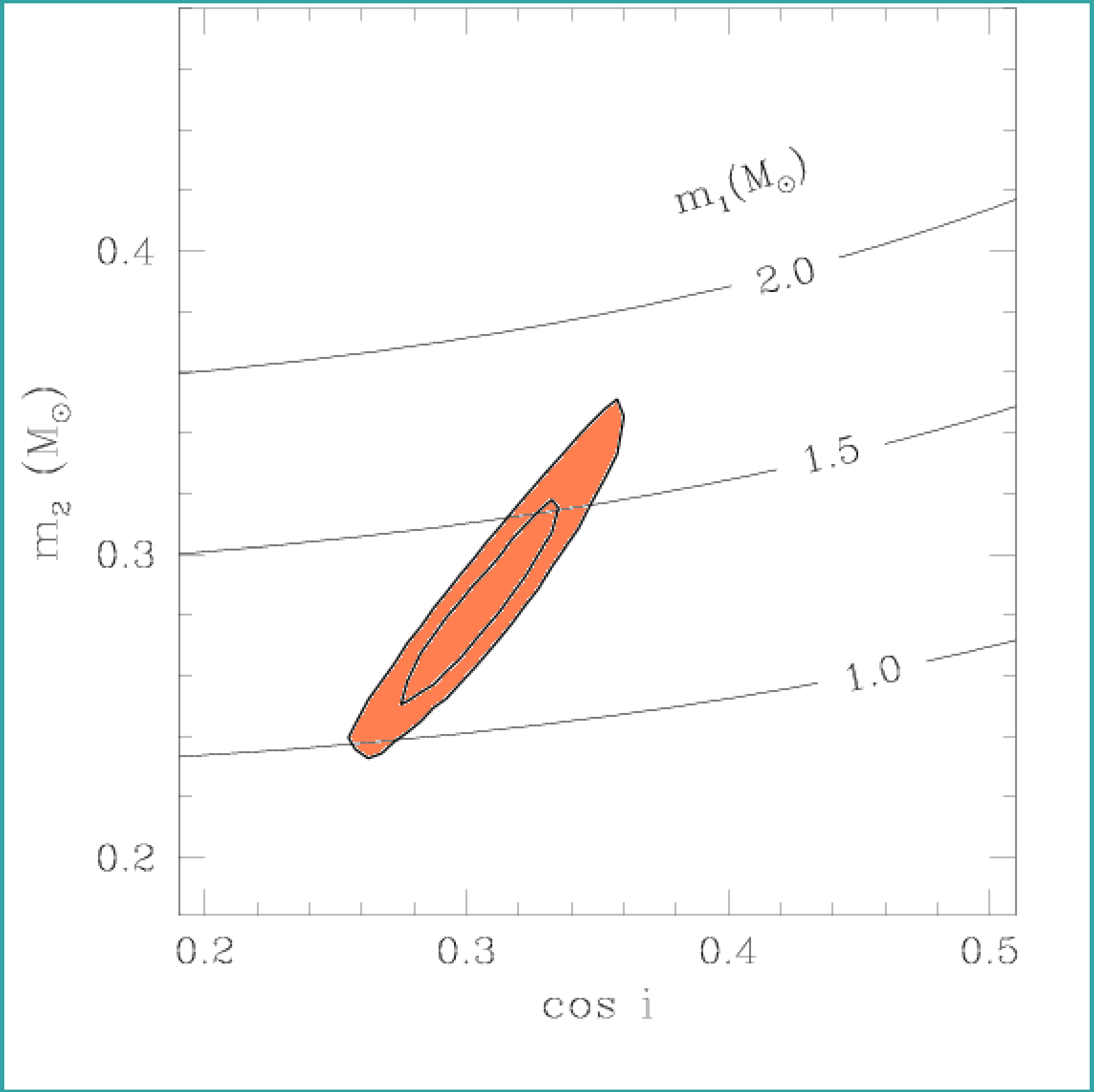


Timing signature can be partly absorbed into Keplerian parameters -- unless the orbit is nearly edge-on to the line of sight.

1802-2124:
WD ~ 0.77 ± 0.09M_{Sun}
NS ~ 1.21 ± 0.14 M_{sun}

Ferdman et al., in prep.

Shapiro delay in PSR J1713+0747

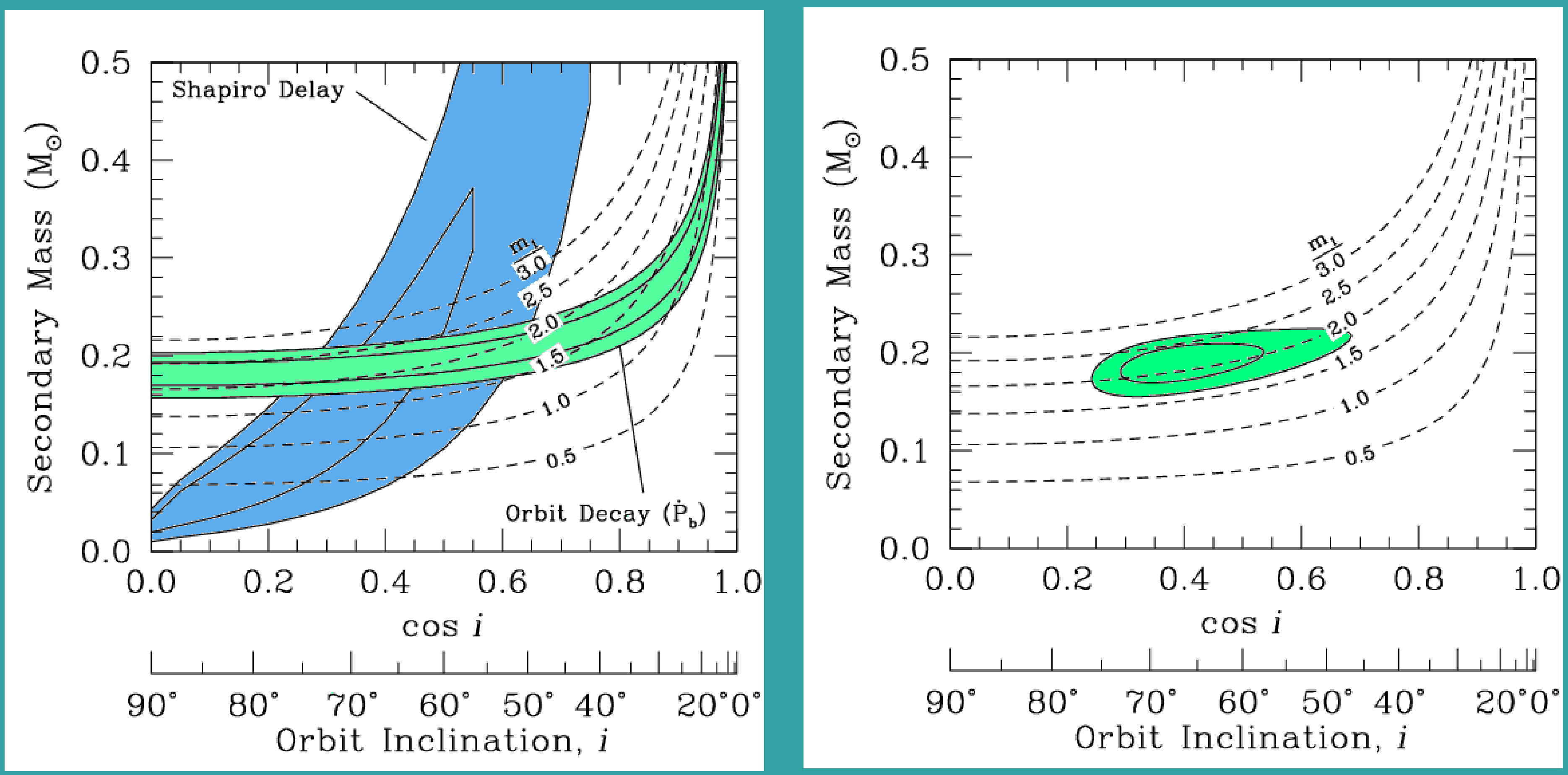


Also other constraints on the inclination angle via geometric effects.

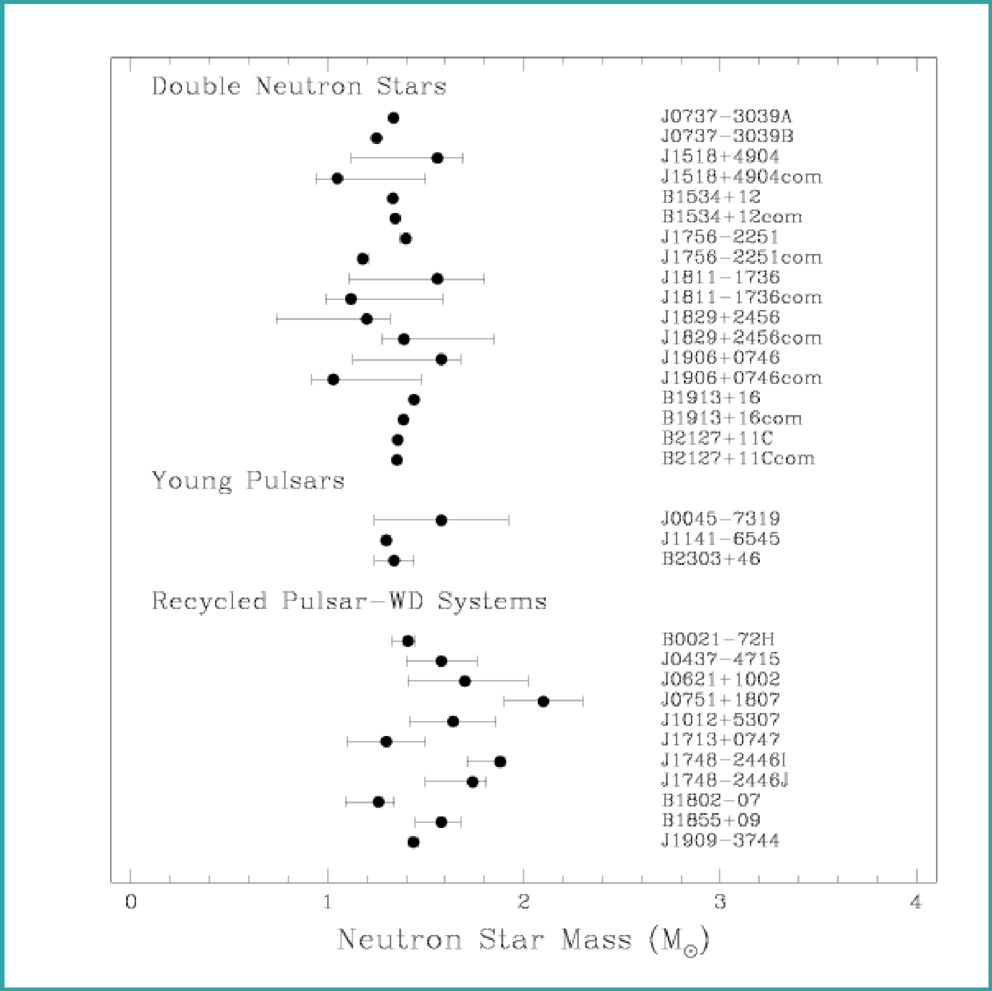
Splaver et al., ApJ 620, 405 (2005).

PSR J0751+1807: Shapiro delay and orbital decay

Pulsar mass is $2.1 \pm 0.2\ M_{Sun}$ at 68% confidence.



Nice et al., ApJ 634, 1242 (2005)



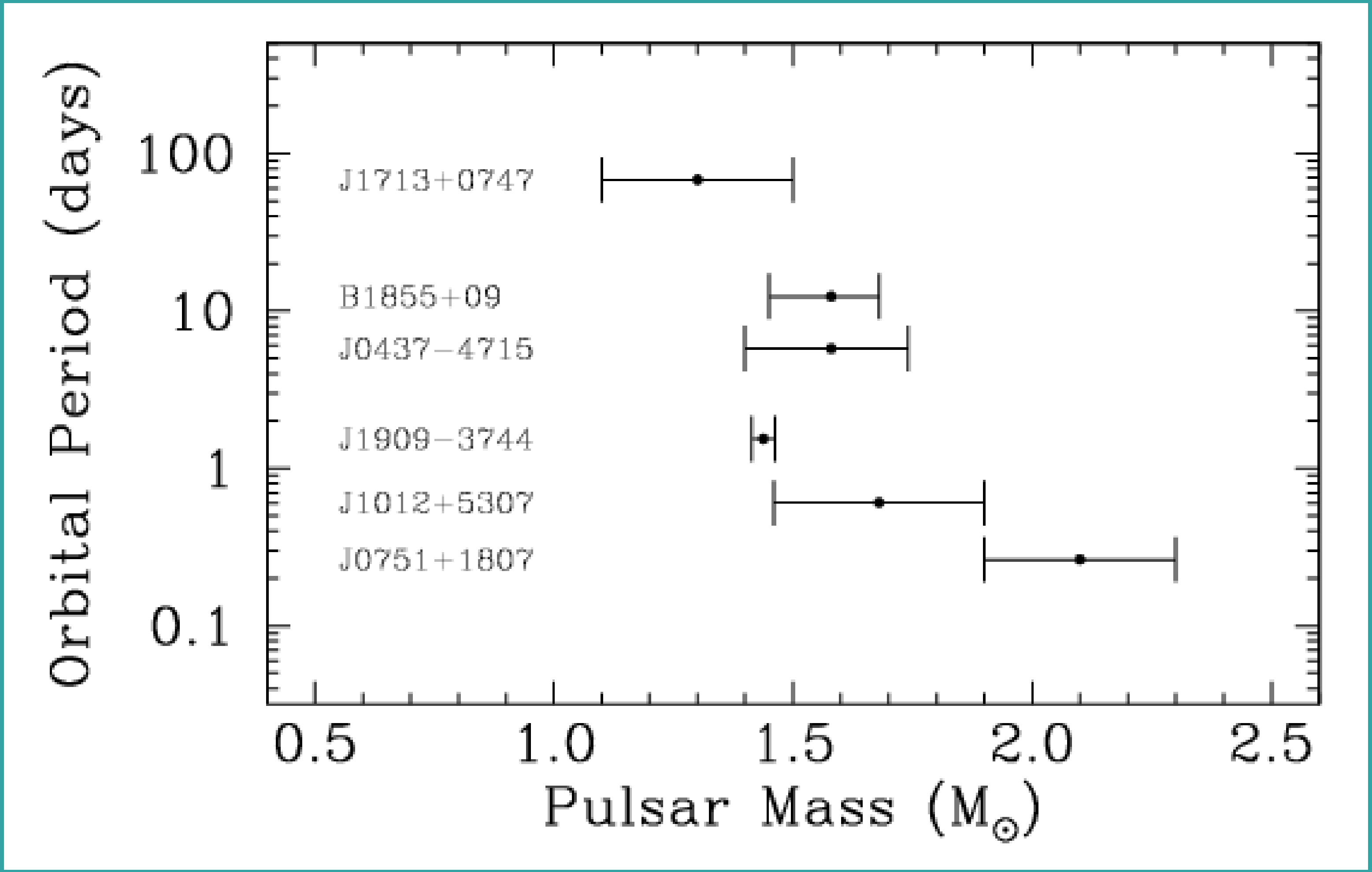
Currently well-measured masses for radio pulsars.

There are several more measurements expected in the next few years!

Are the differences

- significant?
- due to evolution?

For recycled NS—WD systems: an inverse dependence of mass on orbital period? But note that 0751 and 1012 (and maybe 1909?) probably evolved differently from the others...



Nice et al., ApJ 634, 1242 (2005)

Do these masses produce useful constraints on the NS equation of state?

Compare, for example, to the mass-radius plot in Lattimer & Prakash, Science 304, 536 (2004).

Even for J0751+1807, which is the
most massive pulsar, the 95% confidence regions don't rule out very many possible EOS.

Future Prospects for Mass Measurements

- J0751+1807: orbital period derivative improves as time$^{-5/2}$ so there should be good improvement within a few years.

- J0737-3039: advance of periastron is so precisely measured that we should (in 5—10 years) be able to measure the contribution from spin-orbit coupling and get the moment of inertia of pulsar A (Kramer et al., in prep).

- Expect to measure time dilation (γ) in at least two other systems: Terzan 5 I and J1906+0746 (Lorimer et al. 2006).

- Many of the existing measurements will be refined through long-term timing, and other new measurements will also be possible, thanks to wideband coherent dedispersion.

- Long-term: stay tuned for results from the SKA!