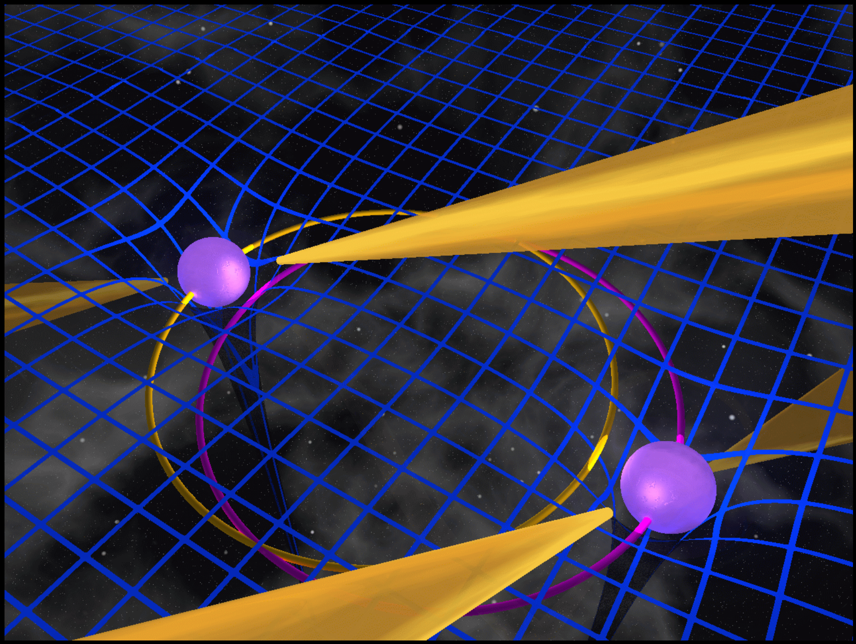
No Longer!

The Double Pulsar

Maura McLaughlin
West Virginia University

22 January 2013

Collaborators: Kramer (MPiFR), Stairs (UBC), Perera (WVU), Kim (Seoul), Rosen (WVU), Lyutikov (Purdue), Freire (MPiFR), Ferdman (McGill), Lomiashvili (Purdue), Gourgouliatos (Purdue), Breton (Southampton), Manchester (ATNF), Kaspi (McGill), Burgay (Cagliari), Possenti (Cagliari), Lyne (Manchester), Ransom (NRAO)



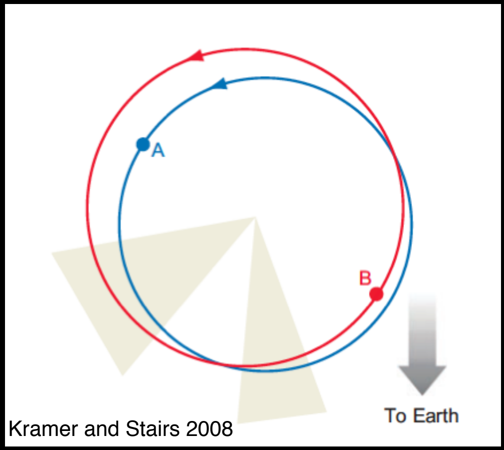
Aspen January 2004

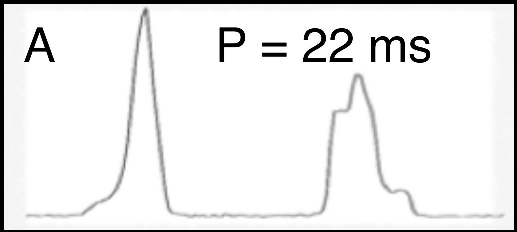
The most relativistic pulsar binary ever!

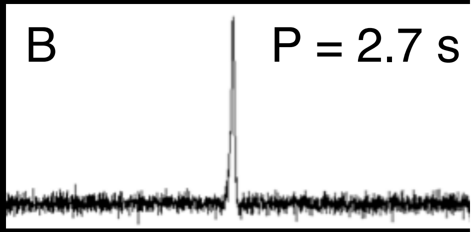
- Discovered in 2003 with Parkes, with B bright in two ~15 min orbital phase regions.
- We can measure two orbits ➔ mass ratio

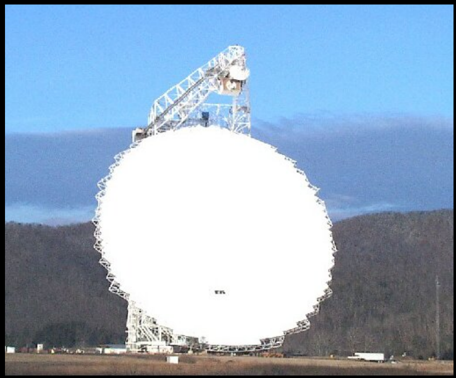
  ($r=x_b/x_a=m_a/m_b$ in all theories of gravity)
- Huge orbital precession of 17 deg/yr

  (4x larger than Hulse-Taylor and 140,000x larger than Mercury!)
- Nearly edge-on orbit with $i = 88.7^{o}$.
- Orbital period of 2.45 hours, with separation of 3 lt-s.
- Orbit shrinking by 7 mm/day due to GW emission.
- Nearby, with VLBI distance of 1.1 kpc.
- Edot of A > 1000 x Edot of B







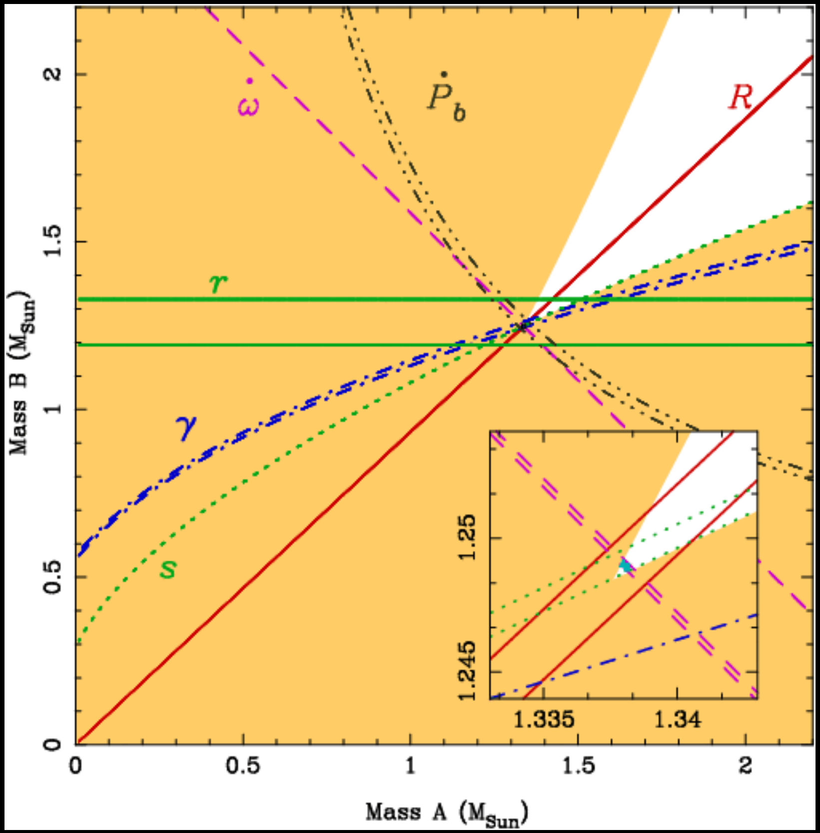


Nearly 10 years of monthly GBT observations!

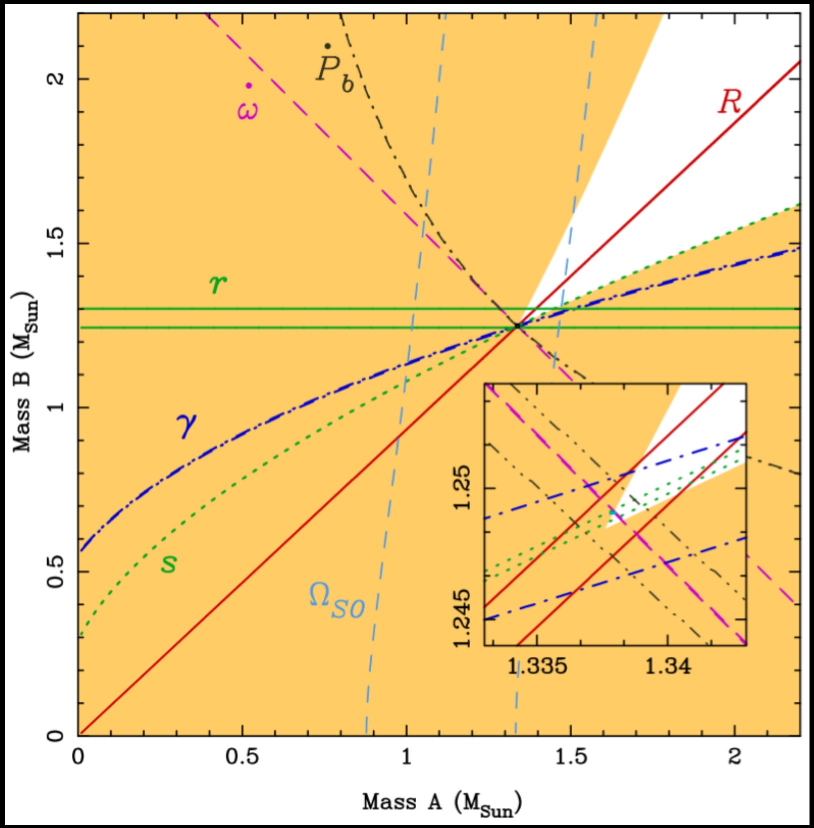
(Thanks Paul and Scott!)

The Money Shot

Kramer et al. 2006



Kramer et al. in preparation



P (ms) = 22.699378599621 3 ± 0.0000000000002 (measured to 0.2 picoseconds!)

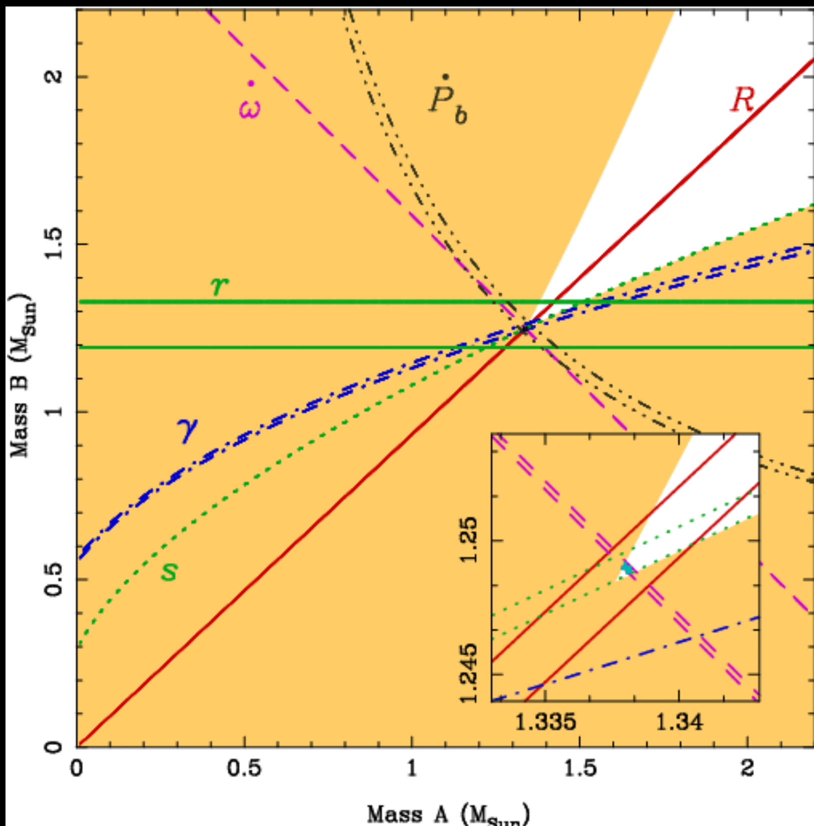
P_b (d) = 0.102251562452 ± 0.000000000008 (i.e. 2.45h measured to 691 ns!)

dP_b/dt = (-1.248±0.001) x 10^{-12} - agreement with GR at 0.1%

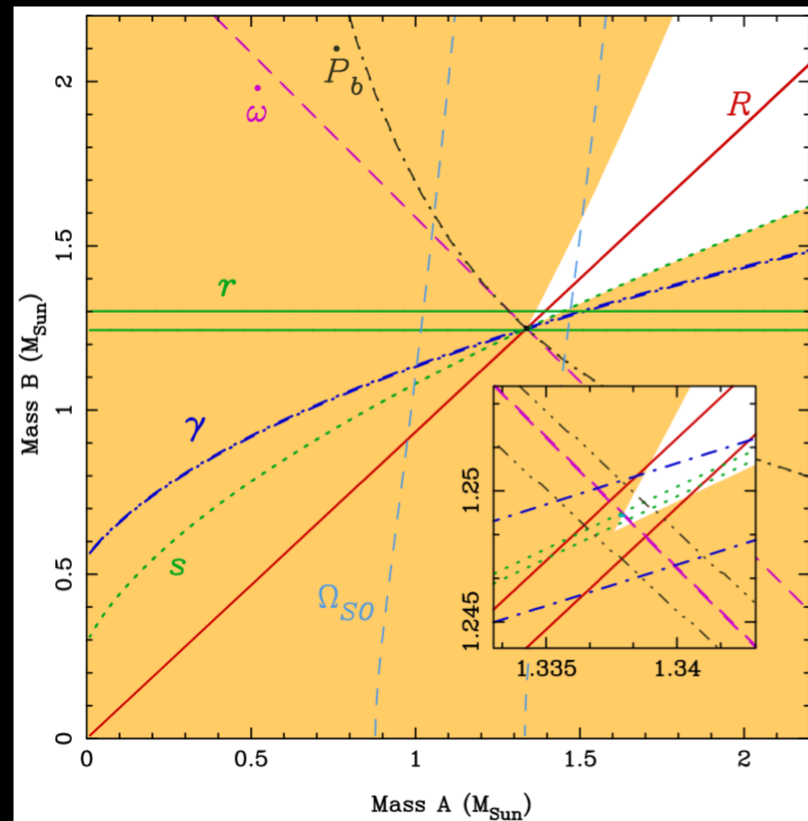
m_A= (1.3381±0.0007) $M_\odot$ and m_B= (1.2489±0.0007) $M_\odot$

Latest Tests of GR

Kramer et al. 2006



Kramer et al. in preparation



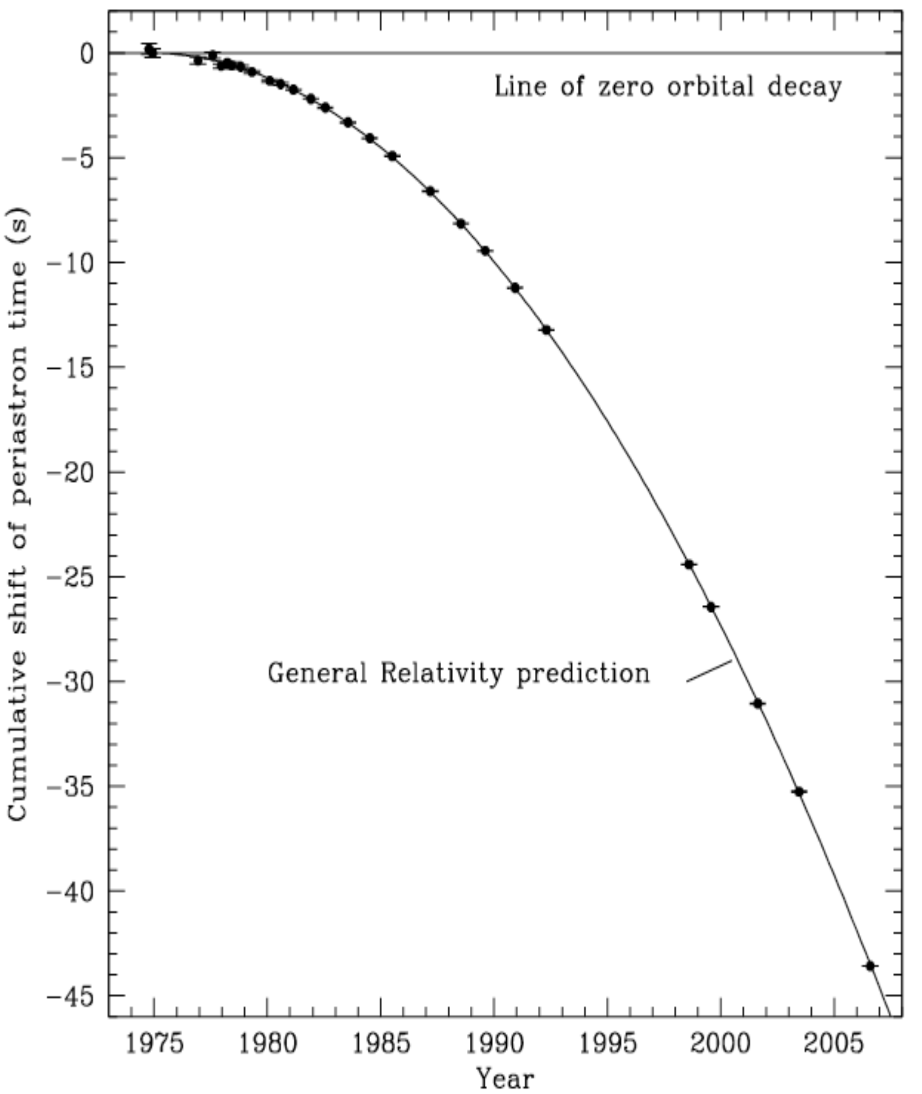
Expected/Observed: 1.000(2) for γ , 1.000(1) for dP_b/dt, 0.98(2) for r, and 1.0000(5) for s.

Measurement of s ➔ agreement with GR to 0.05%!

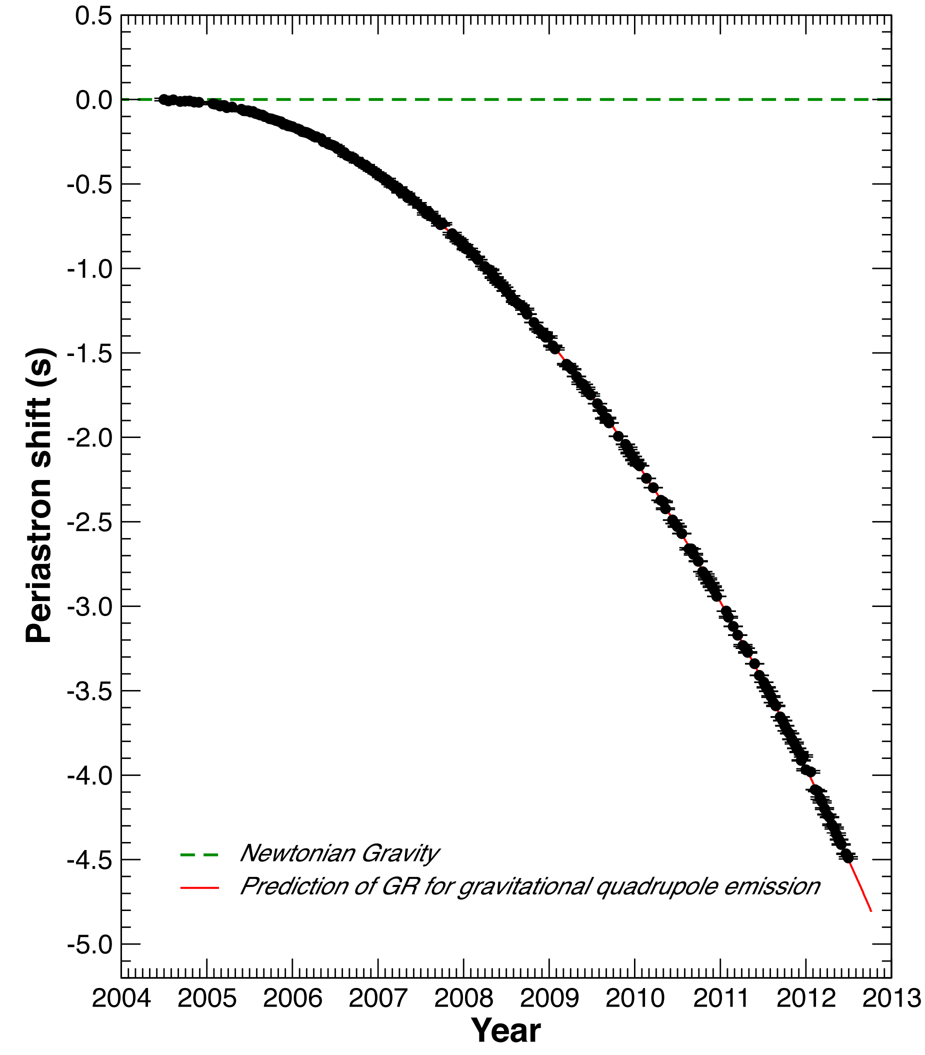
Precision will continue to improve, superseding solar system tests.

Best proof for GWs so far

Weisberg et al. (2010)



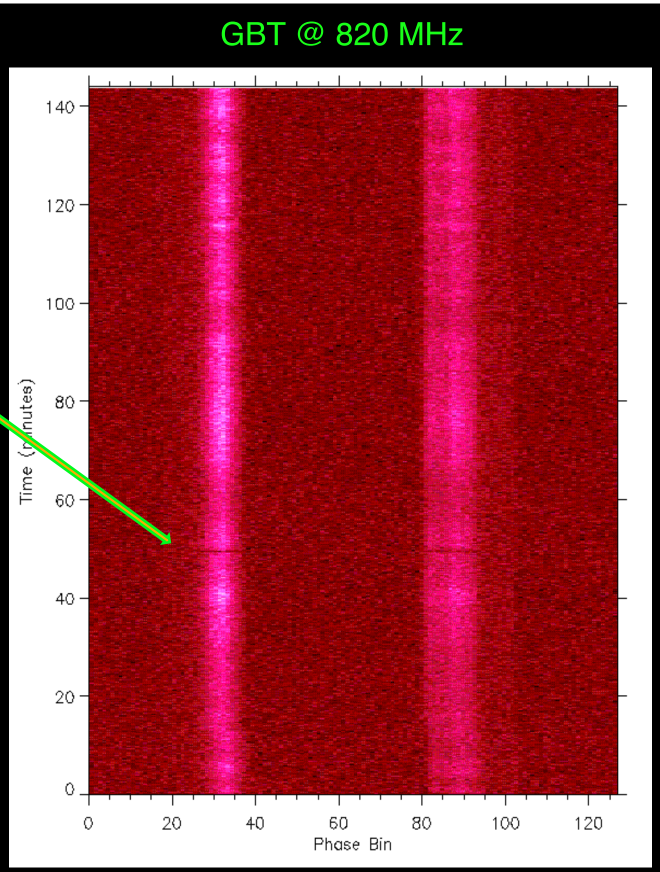
Kramer et al. (in prep.)

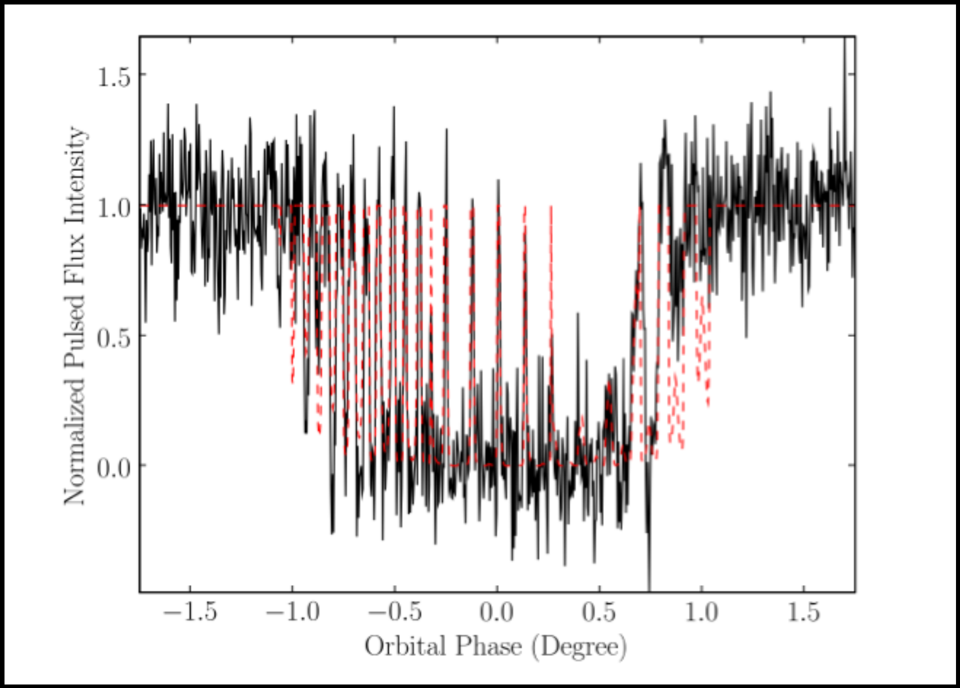


Influence of B on A: Eclipses

A is eclipsed for ~ 30 seconds per orbit.

Occulting region of 0.05 lt-s; 10% of light-cylinder radius (~10^{10} cm) of B.





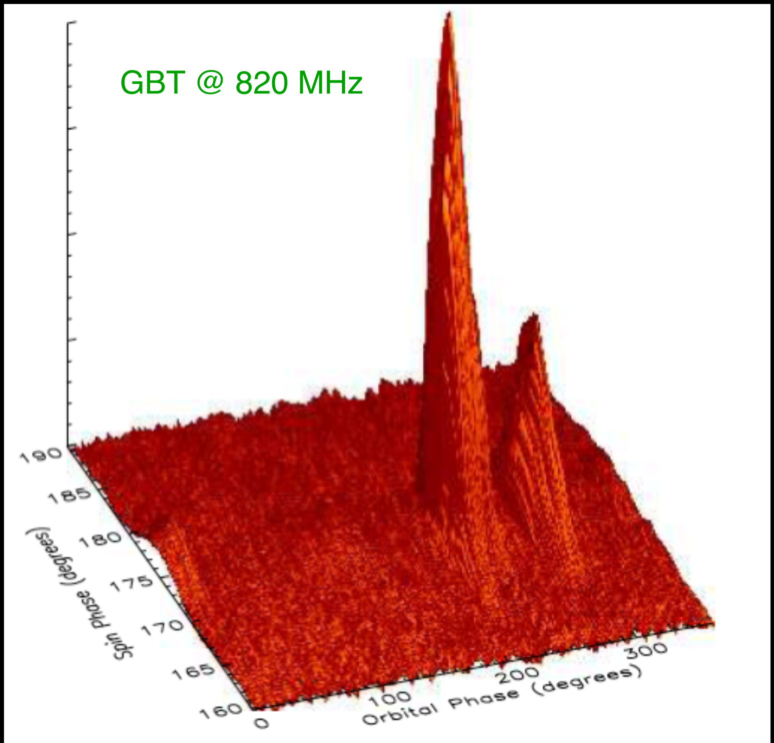
Can model eclipse shape to derive geometrical parameters of B (α = 70°, θ = 130°) and measure 5° yr^{-1} rate of geodetic precession of B (Breton et al. 2008)

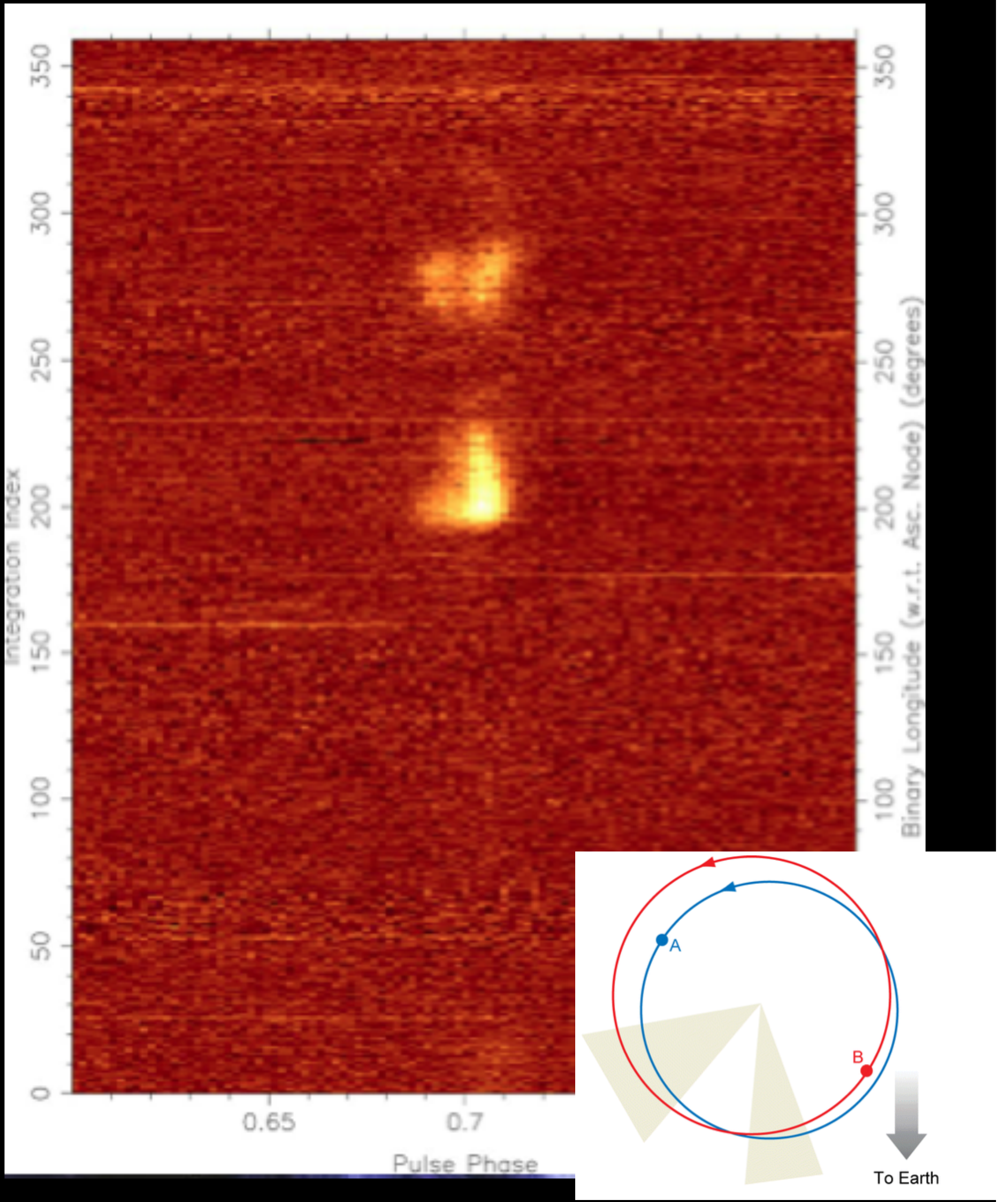
Pulsar B field is dipolar!

Influence of A on B: Bright Phases

B bright at only two orbital phases.

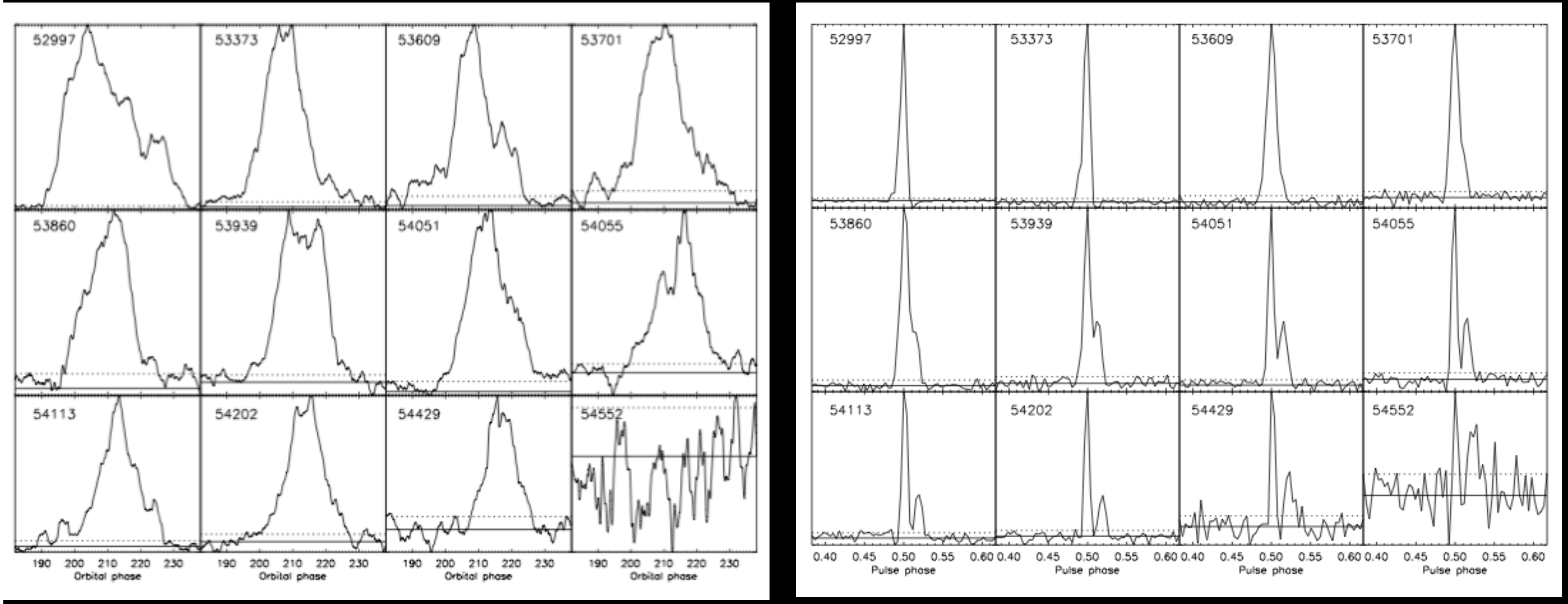
Due to A distorting B's magnetosphere (Lyutikov 2005).





Influence of A on B: Bright Phases

B shows dramatic lightcurve and pulse profile changes across orbit and with time due to periastron advance (17^o yr^{-1}) and geodetic precession (5^o yr^{-1}) .



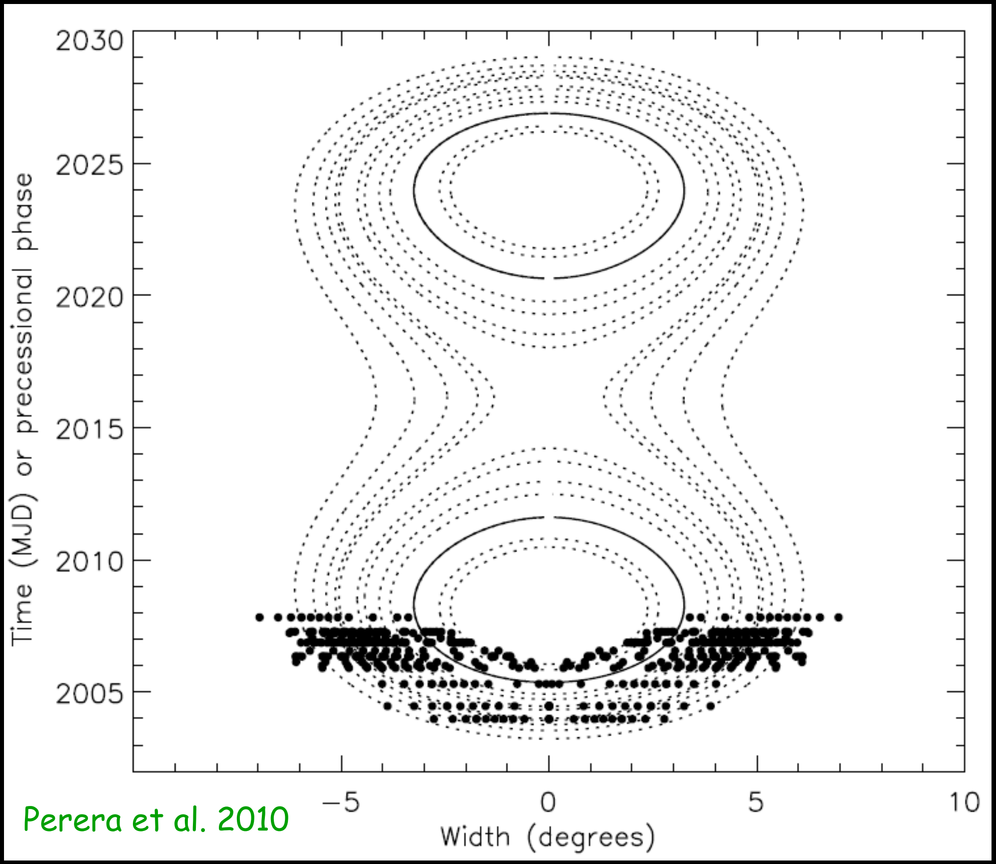
Lightcurves (left) and pulse profiles (right) of B during BP1 from December 2003 to March 2008 (Perera et al. 2010).

Geodetic Precession: Pulse Profiles

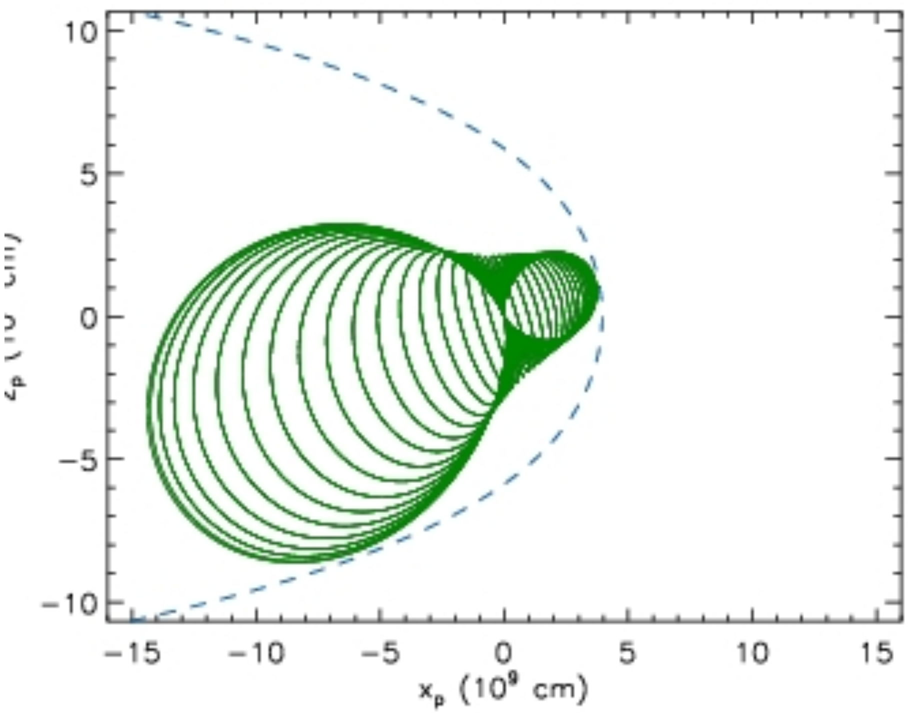
We can fit the pulse profile evolution to a geometrical model. We find similar geometrical parameters as from eclipse model fitting ($\alpha = 70^o$, $\theta = 130^o$).

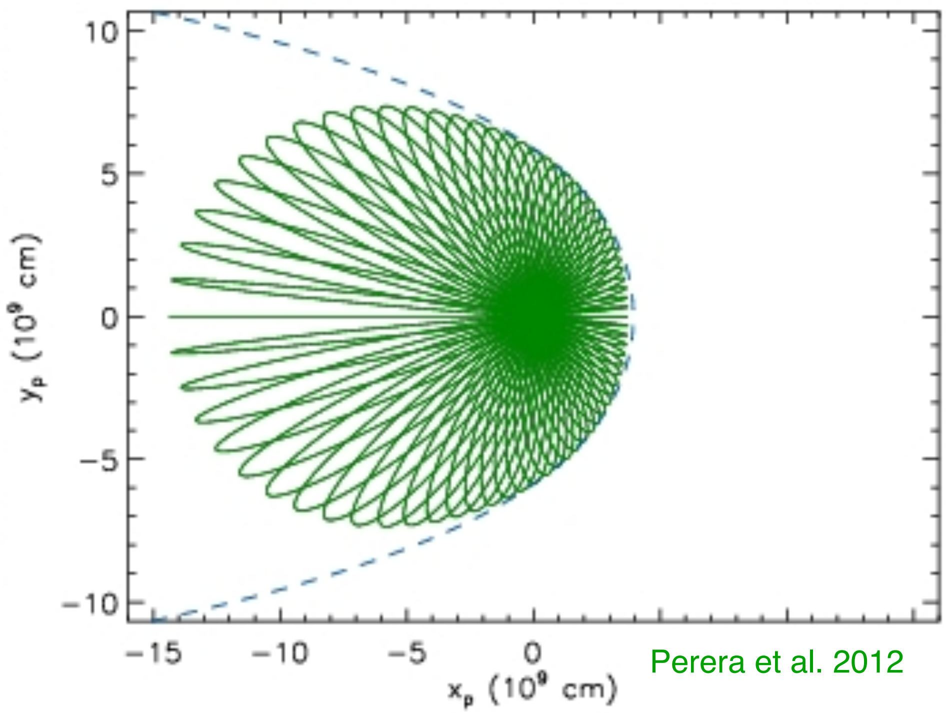
Emission beam is elliptical ($a/b = 2.6$) and only partially filled (intrinsic or extrinsic!)

Radio reappearance is expected to occur in 2024 (with caveats!)



Influence of A on B: Emission Heights



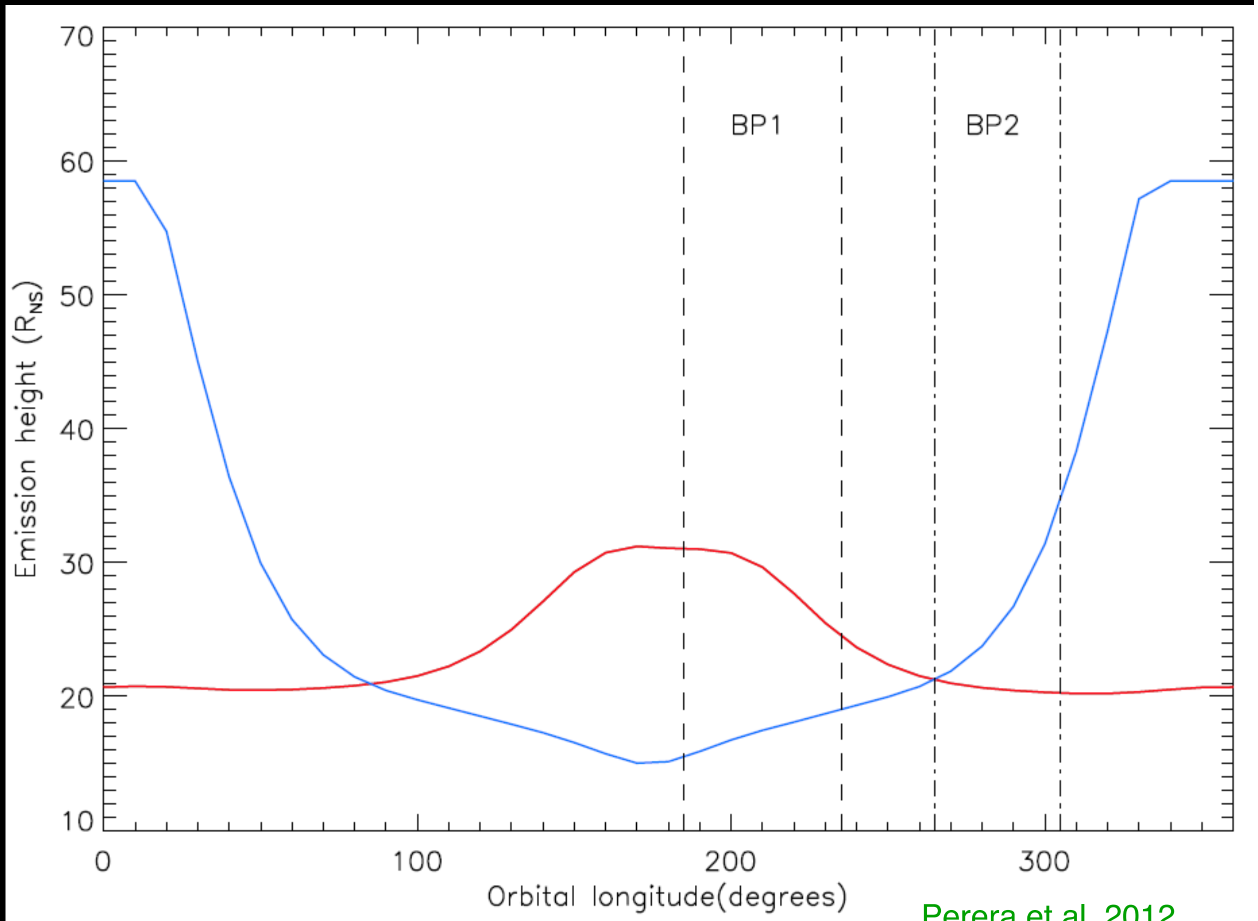


Perera et al. 2012

Bow shock at 4×10^9 cm (30% R_{LC}) from B. Can trace the magnetic field lines structure within this bow shock, given solved geometry. Will change with orbital phase and B spin phase.

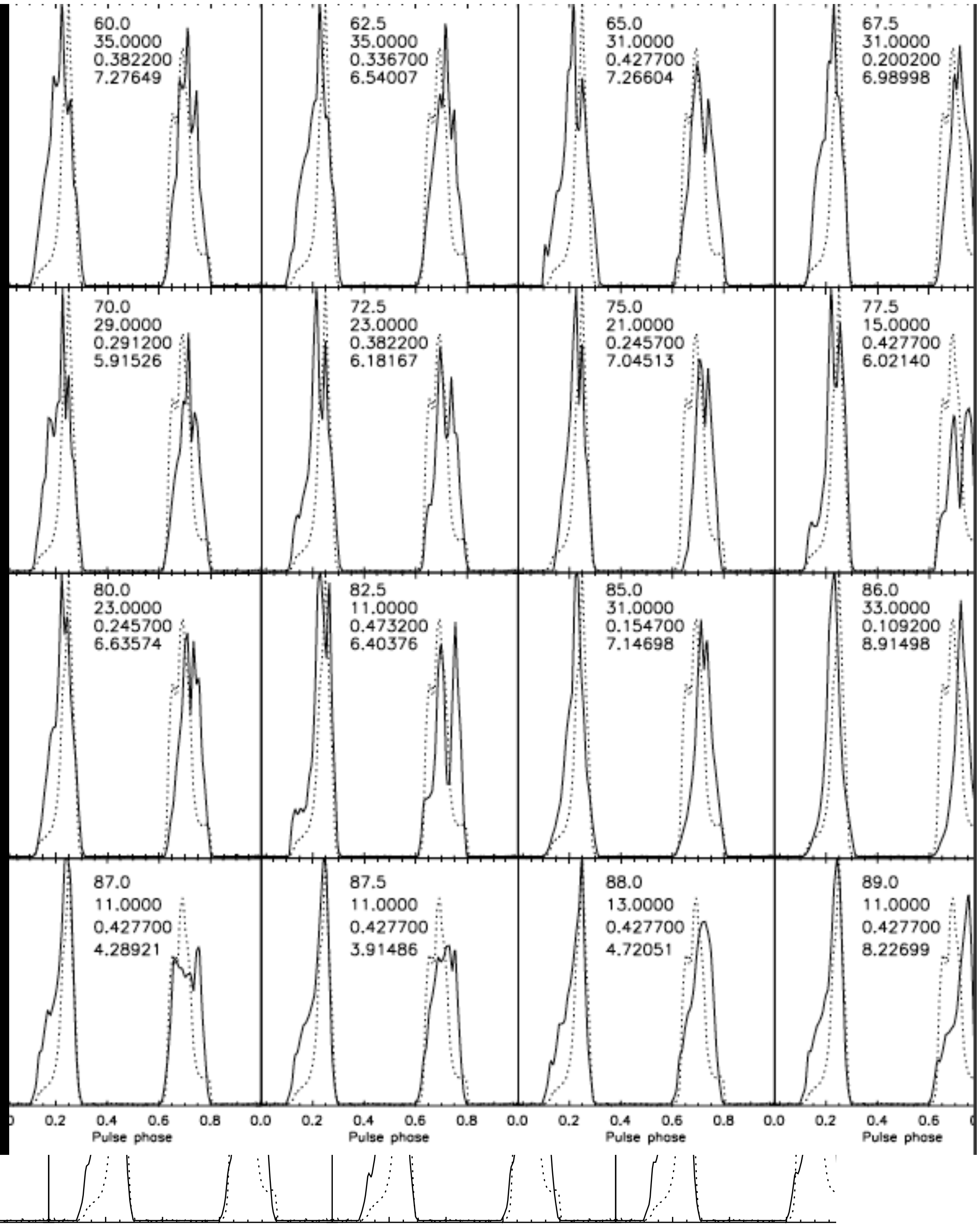
Influence of A on B: Emission Heights

Can estimate (minimum) emission heights given magnetic field structure and shape of pulse profile.



Perera et al. 2012

Similar Models for A



Fits of simulated profiles to measured profiles for two-pole PC model by Ben Perera.

Constraining geometry crucial for LIGO waveform predictions.

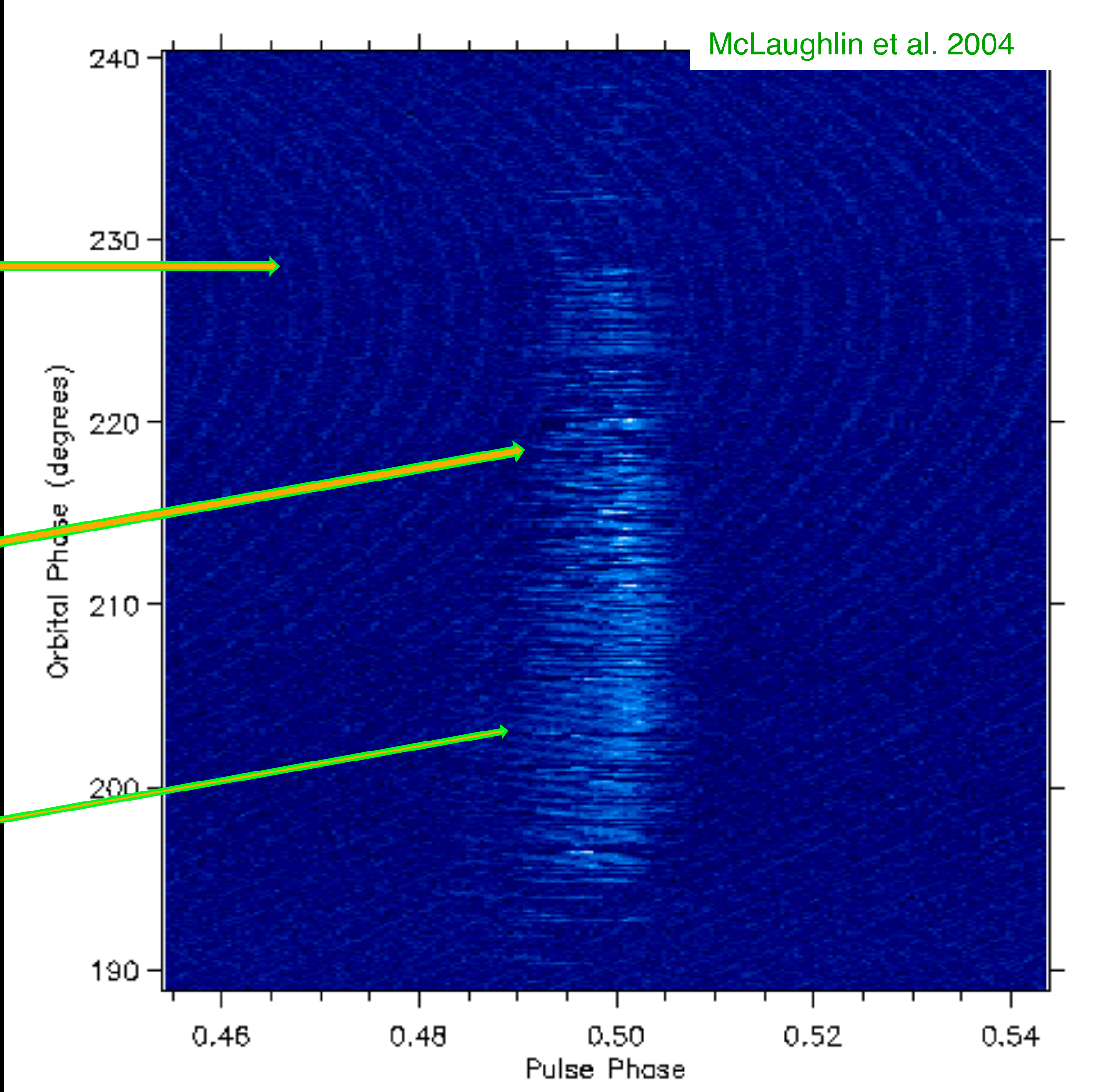
Influence of A on B: Drifting Features

GBT @ 820 MHz

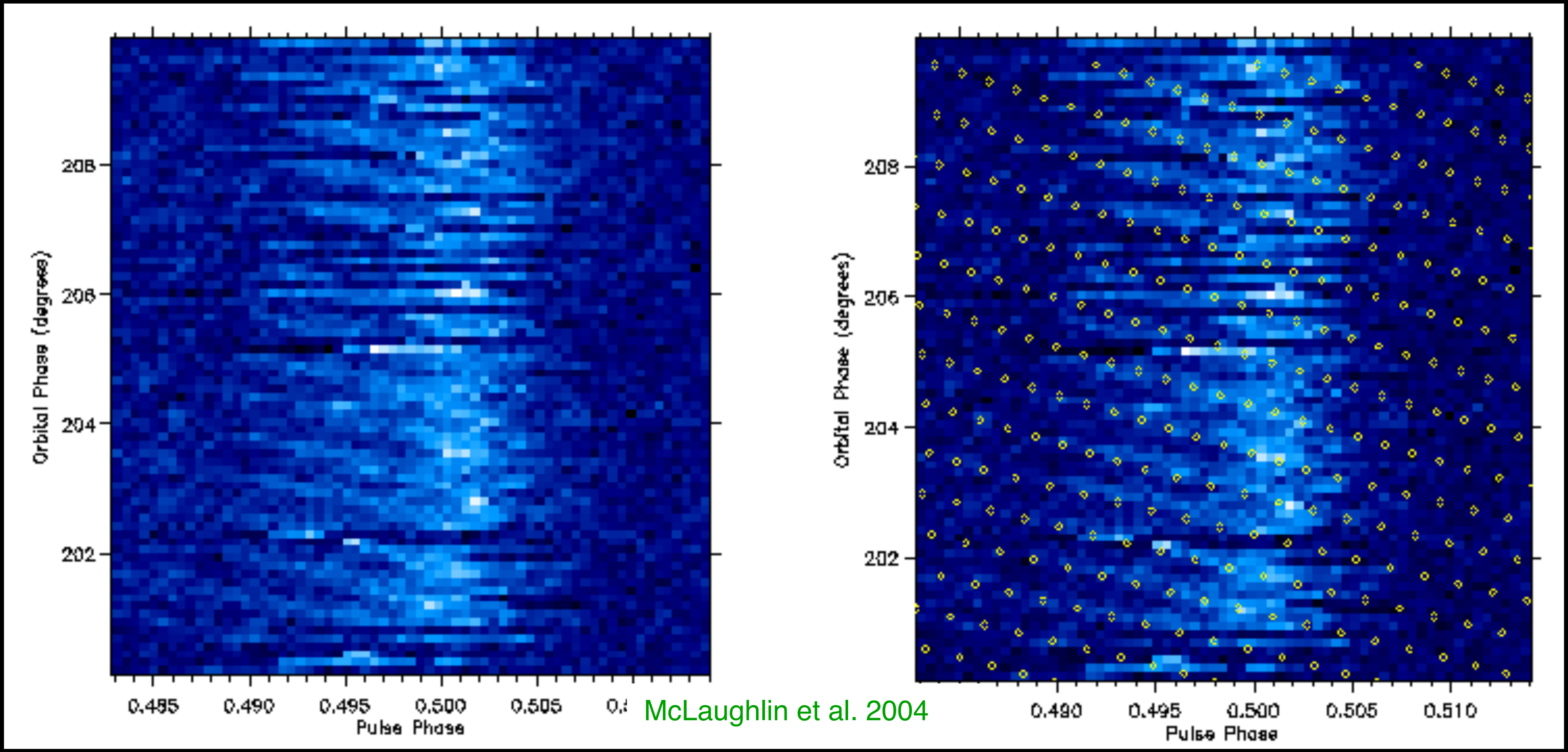
Single pulses from A

Single pulses from B

Drifting



Influence of A on B: Drifting Features



McLaughlin et al. 2004

The drifting is a direct signature of the influence on the EM radiation from A on B!

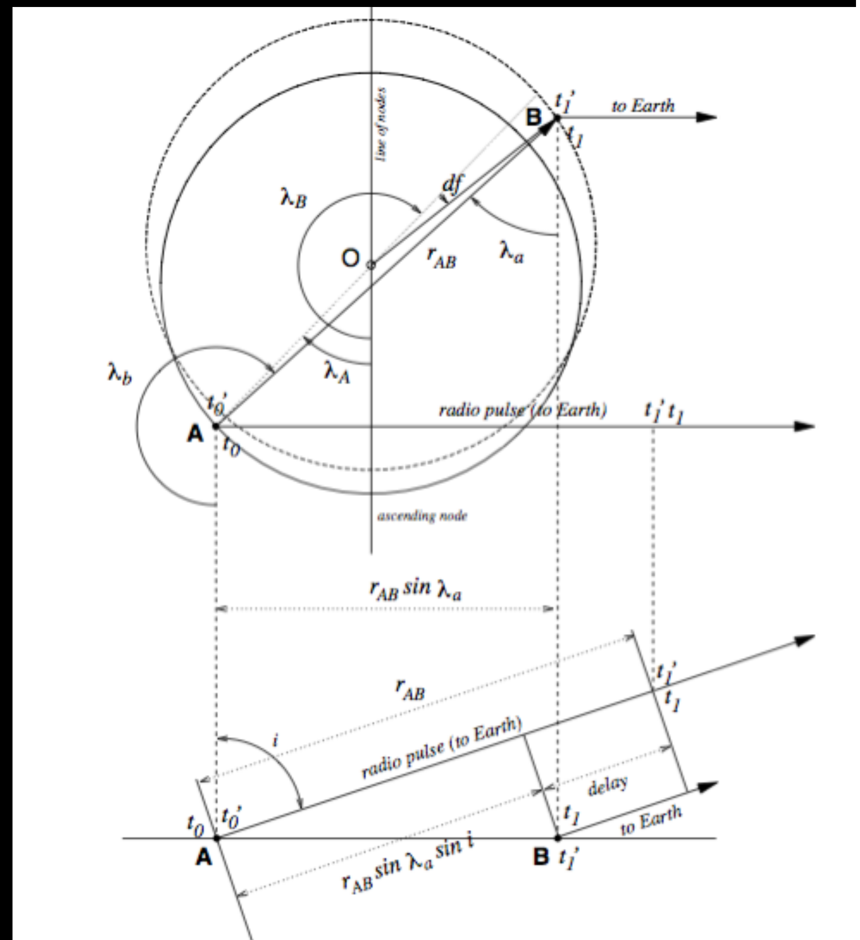
Influence of A on B: Drifting Features

Through a geometrical model (Freire et al. 2009, Rosen et al. in preparation), can fit for:

1) Rotation direction of A

2) Emission altitude in B, ε

3) Angle between A's radio and EM beam, ϕ_e



Response Delay =

$$\Delta(\lambda_A) - K(\lambda_A) = \frac{\epsilon}{c}(\sin\lambda_a \sin i - 1) \pm P'_A \left(\frac{\lambda_a}{2\pi} - \frac{\phi_e}{2\pi} - \frac{1}{4}\right)$$

Influence of A on B: Drifting Features

Through a geometrical model (Freire et al. 2009, Rosen et al. in preparation), can fit for:

1) Rotation direction of A

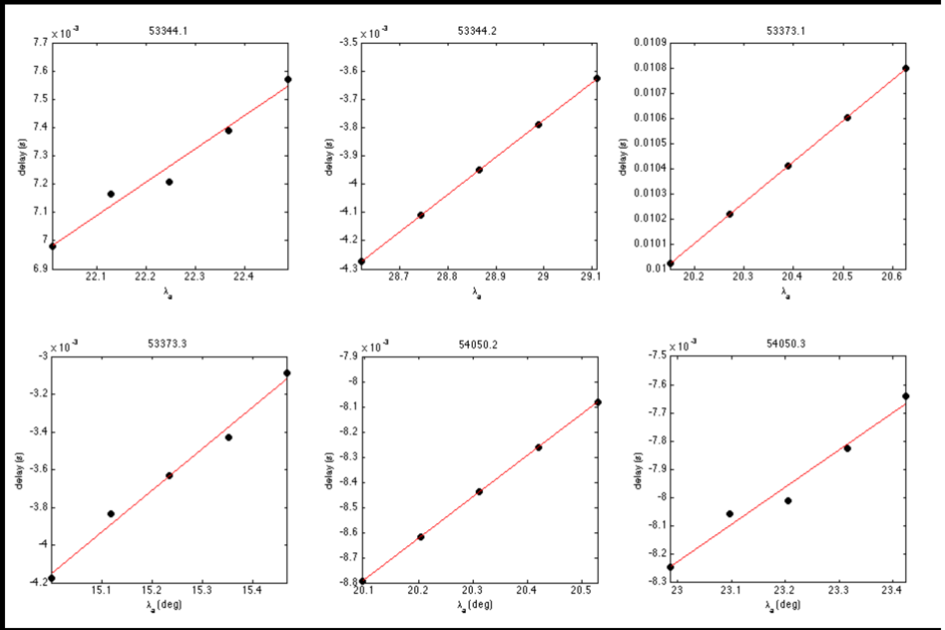
   likely in direction of orbit

2) Emission altitude in B, ε

   ~500 R_{NS} (within the bow shock)

3) Angle between A's radio and EM beam, ϕ_e

   small and varying



preliminary!

Response Delay =

$$\Delta(\lambda_A) - K(\lambda_A) = \frac{\epsilon}{c}\left(\sin\lambda_a \sin i - 1\right) \pm P'_A\left(\frac{\lambda_a}{2\pi} - \frac{\phi_e}{2\pi} - \frac{1}{4}\right)$$

Conclusions

After nearly ten years, the Double Pulsar is still providing new insights.

We can fit B pulsar data with an elliptical, partially filled beam and can determine the geometrical parameters of the system.

Determining these parameters is crucial for LIGO waveform generation!

B is expected to reappear in 2024.

We see evidence for the direct modulation of B pulsar emission through the EM field of A.

We estimate B emission heights of ~100 R_{NS} (minimum) through geometrical modeling and ~500 R_{NS} through drift-band fitting.

Advances in timing and GR tests will come with improved B timing precision.