MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut für Radioastronomie

Towards Improving and Understanding the Timing of PSR J0737–3039B

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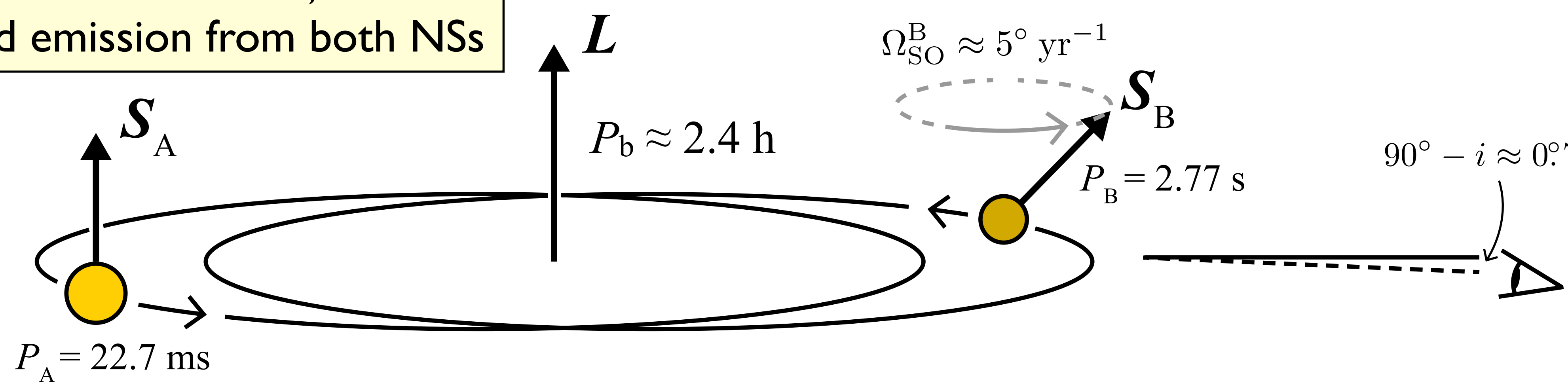
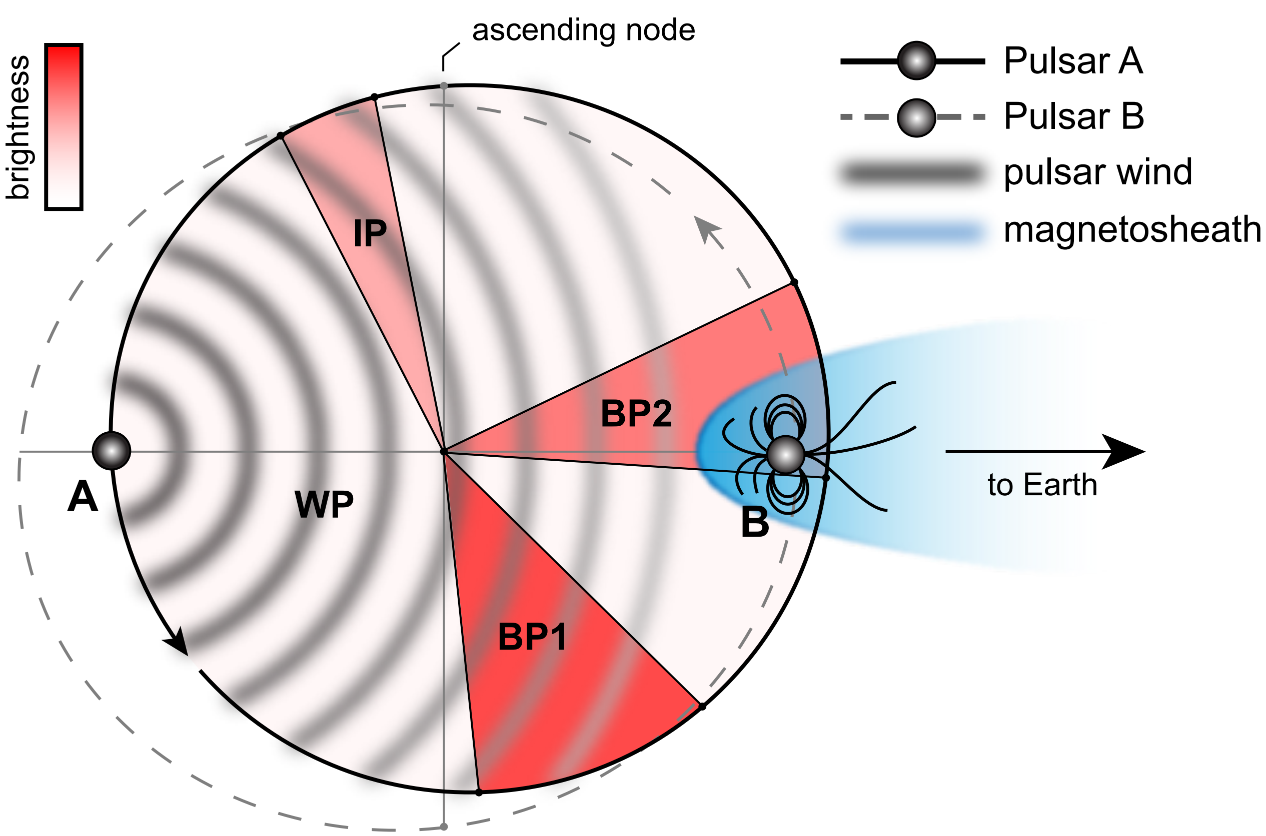
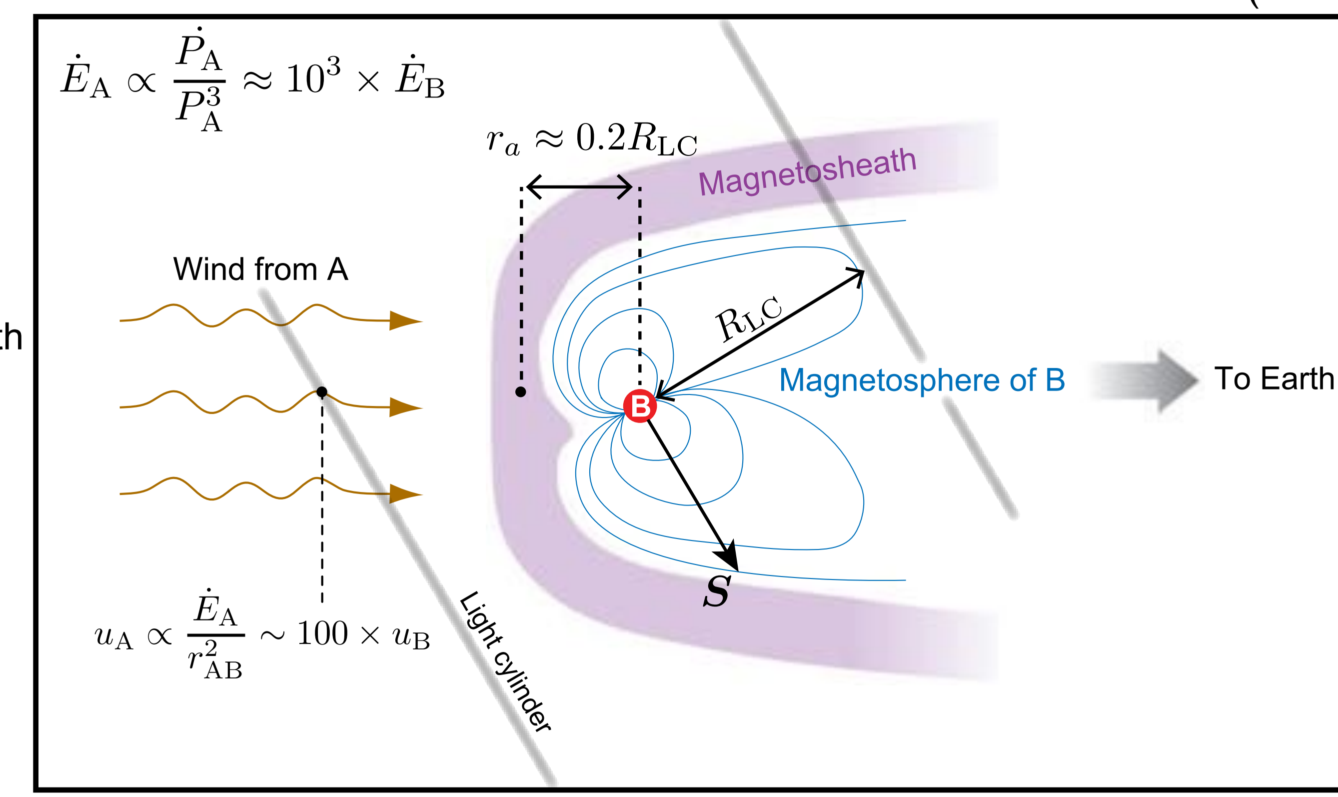
The Double Pulsar

The only system we know to date, where we observe pulsed emission from both NSs



Kramer & Stairs (2008)



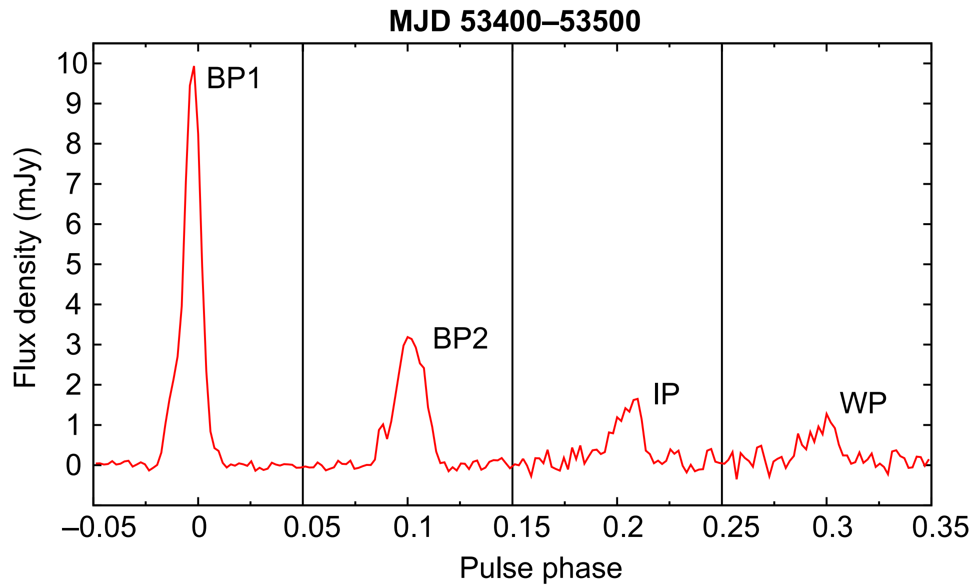


- Pulsar A distorts Pulsar B's magnetosphere with its relativistic particle wind
- Pulsar A is sill visible and a very stable timer
- Pulsar B: precessed out of view in 2008

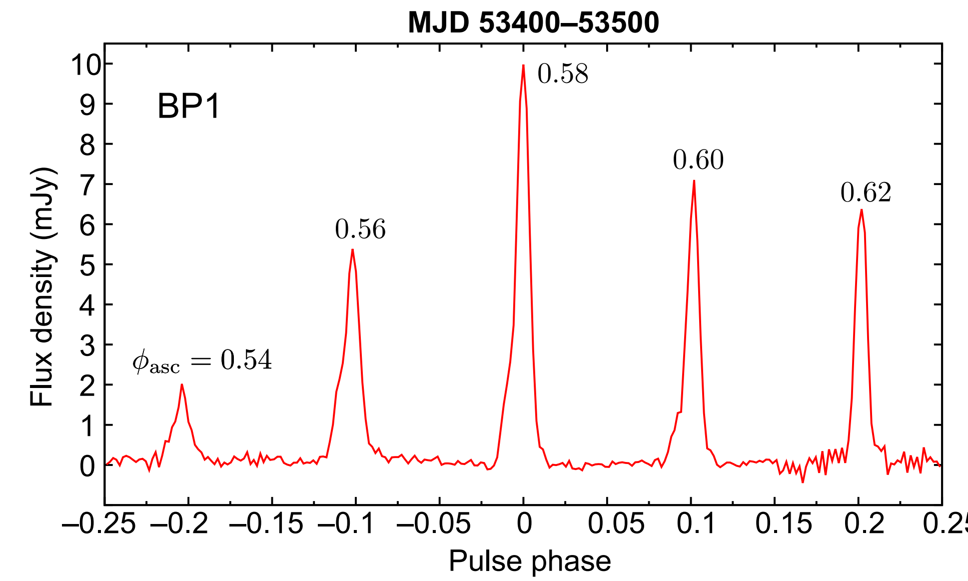
  e.g. *Breton et al. (2008)*

Timing

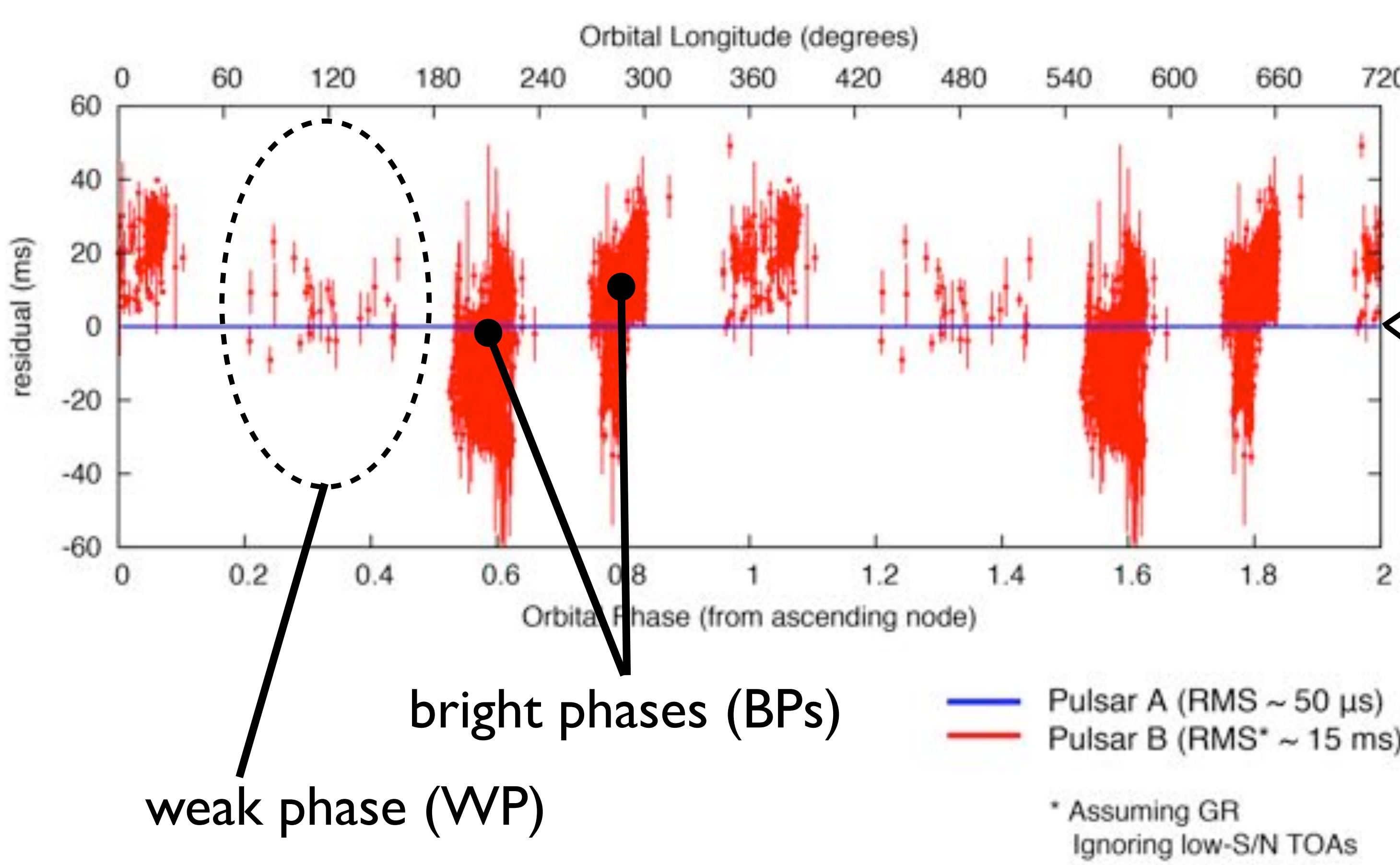
Strong profile evolution **across the orbit** …



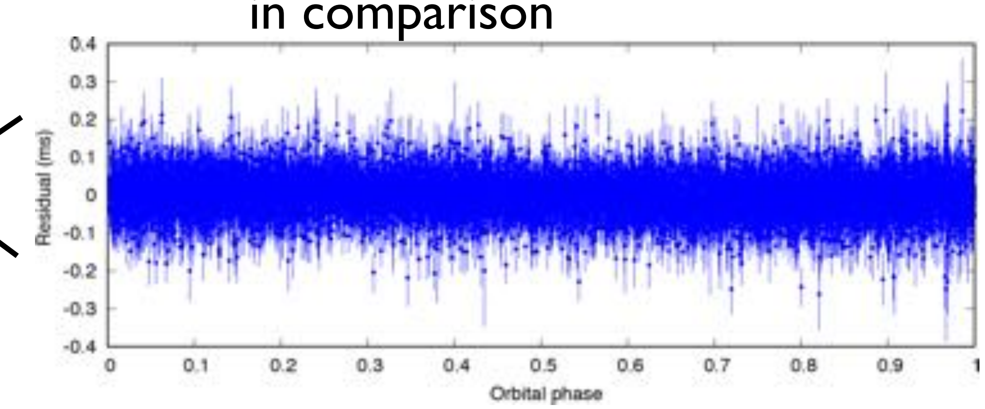
… and **across each bright phase**



This results in **poor timing precision**, due to systematics



Pulsar A is a great timer in comparison



$$x_{\rm A}^{\rm obs} = 1.415032 \pm 0.000001 \ \ \text{lt-s}$$

$$x_{\rm B}^{\rm obs} = 1.5161 \pm 0.0016 \ \ \text{lt-s}$$

(Kramer et al. 2006)

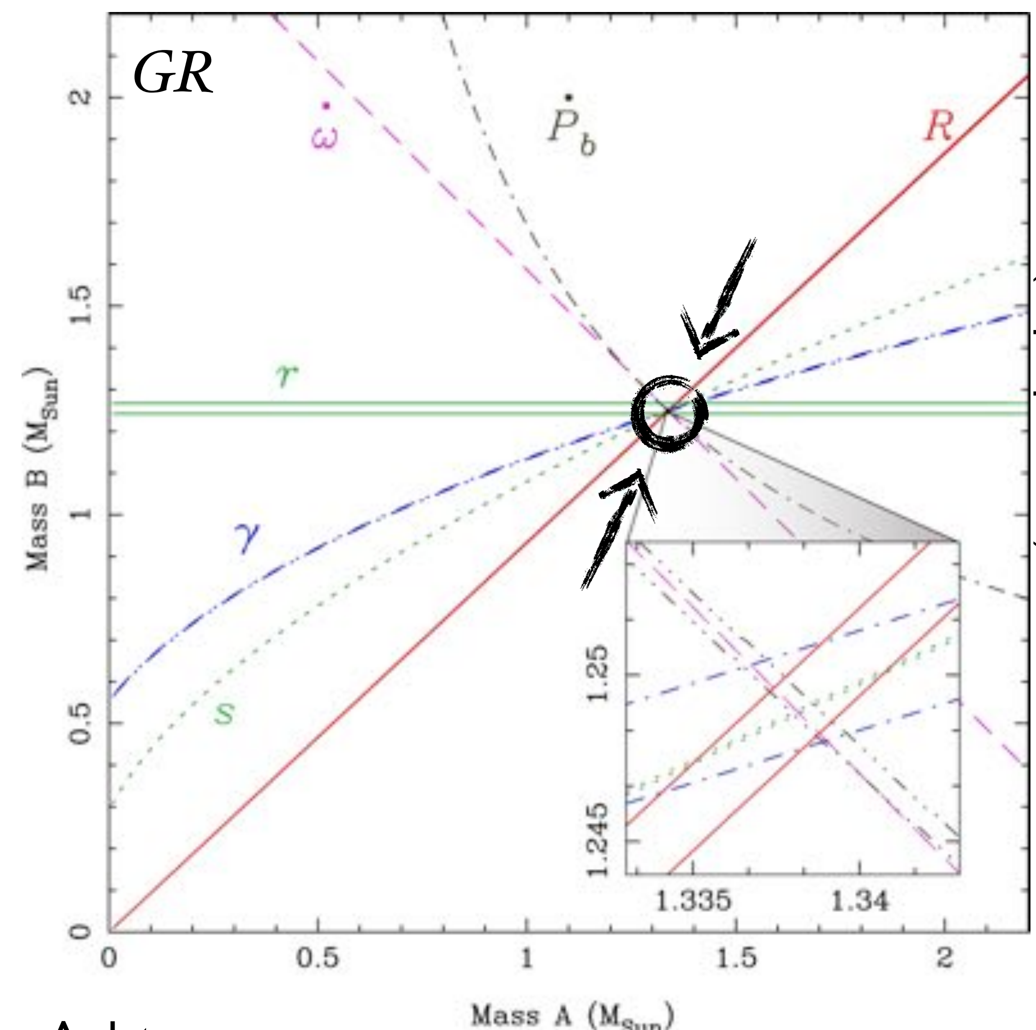
Tests of GR

The timing precision of Pulsar A has been employed in tests of GR and alternative theories.

For a wide range of gravity theories, we can express the PK parameters as a function of the Keplerian parameters and m_A and m_B:

$$p_i^{\mathrm{PK}} = f_i(\mathbf{p}^{\mathrm{K}}; m_{\mathrm{A}}, m_{\mathrm{B}})$$

A common intersection of all f_i at the binary's masses **implies that the theory is correct**.



Kramer et al. (in preparation)

$$R = \frac{x_{\mathrm{A}}^{\mathrm{int}}}{x_{\mathrm{B}}^{\mathrm{int}}} = \frac{m_{\mathrm{B}}}{m_{\mathrm{A}}}$$ is:

- **theory independent**
- **poorly constrained** due to Pulsar B timing *

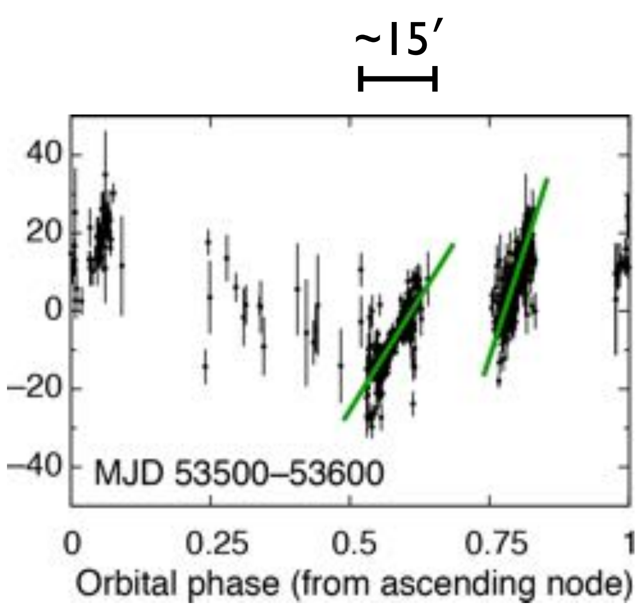
* the precision of the rest of the PK parameters improves with more Pulsar A data

Improving Pulsar B timing will improve the precision of GR tests with this system

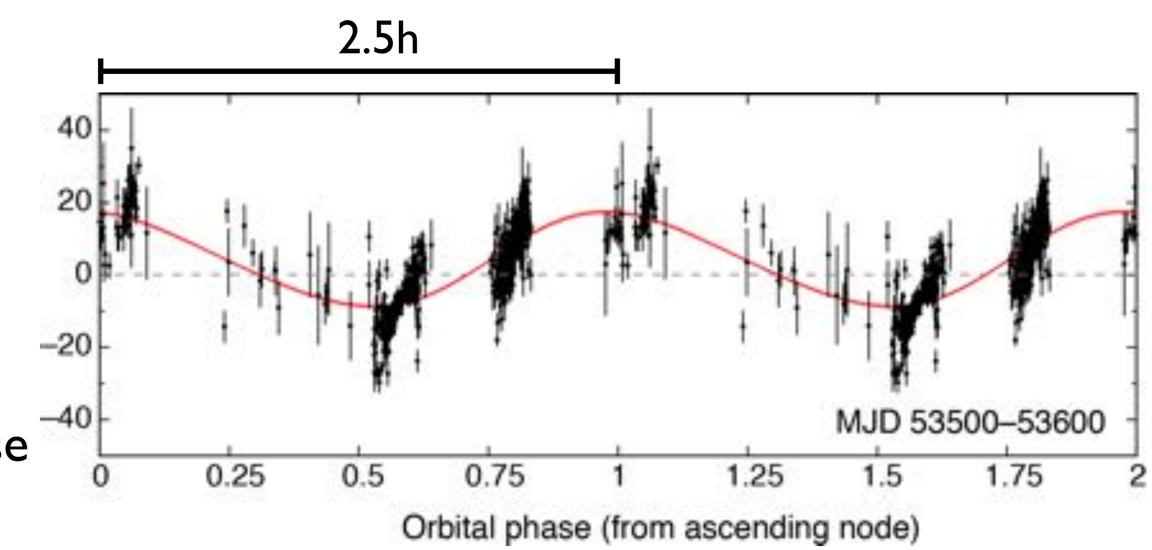
Pulsar B Data

Our data:

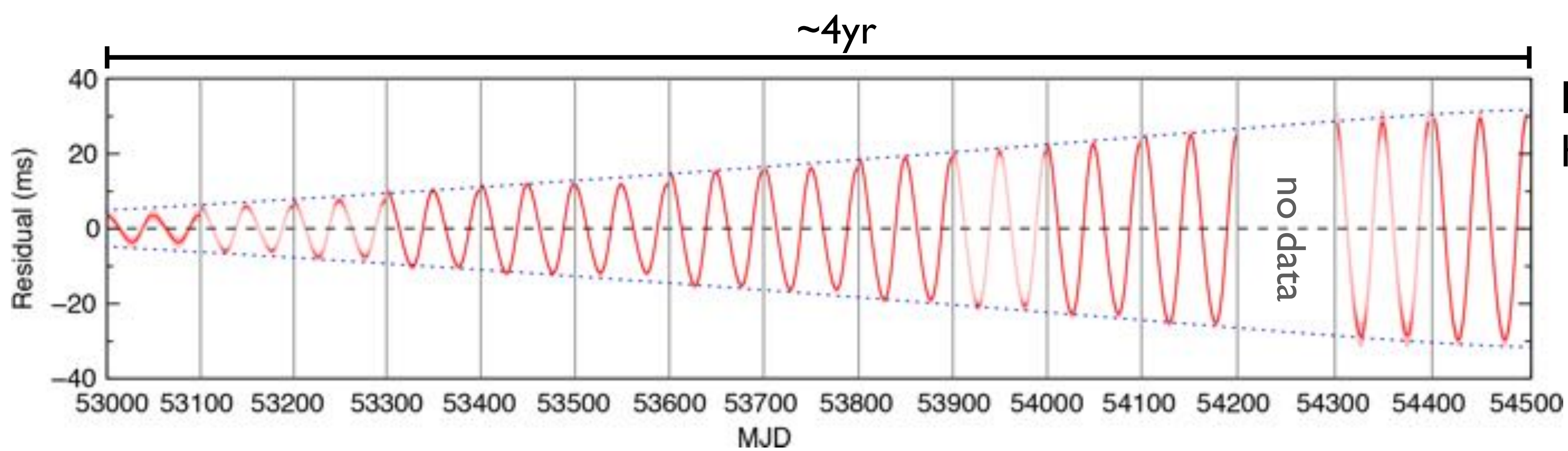
- Observations with the GBT at **820 MHz** and with Parkes at **685 MHz and 1.4 GHz**.
- Data span ≈ **4 years (2004 – 2008)**
- After data selection and RFI excision: **4,115 profiles (flux-calibrated)**
- To map the precessional evolution, we **binned the data** into **15 100-day intervals**



Short-term quasi-linear drifts across each of the BPs



harmonic drift as a function of orbital phase

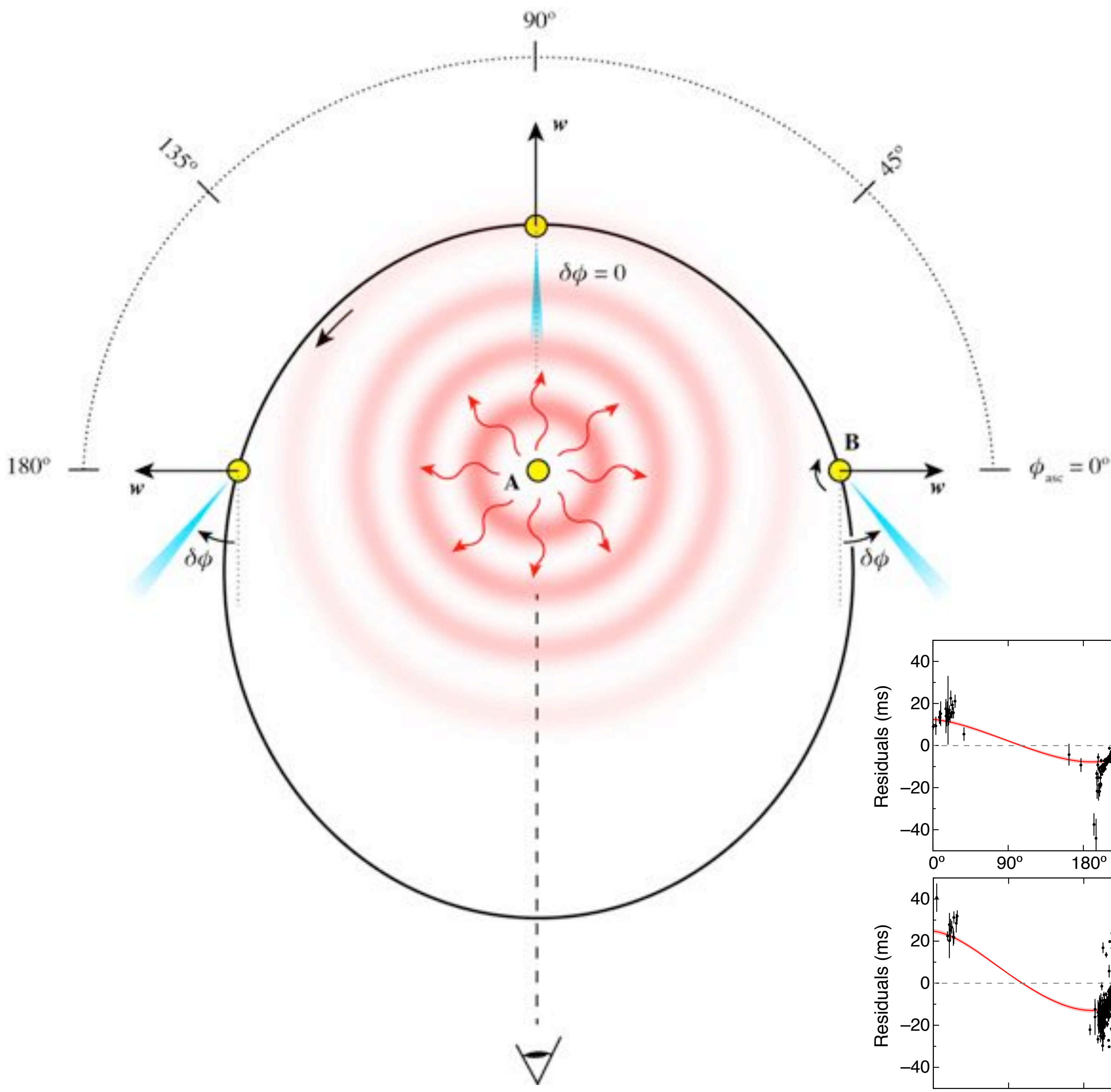


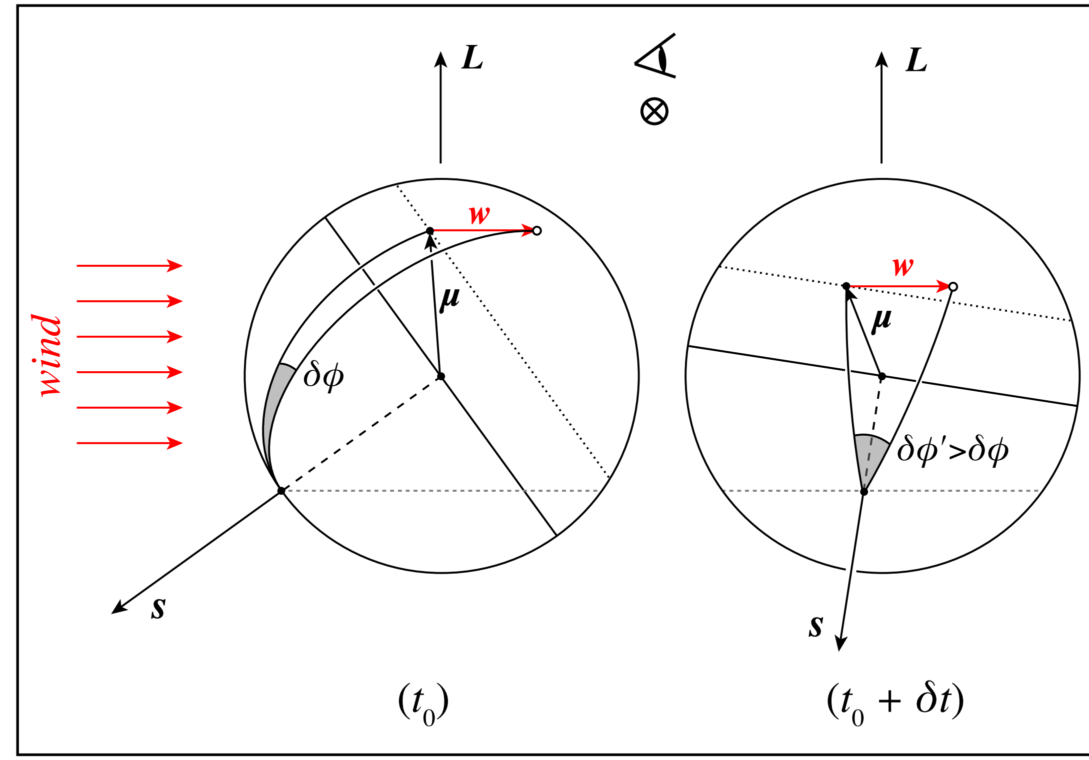
long-term modulation of the harmonic drift's amplitude

Wind Model

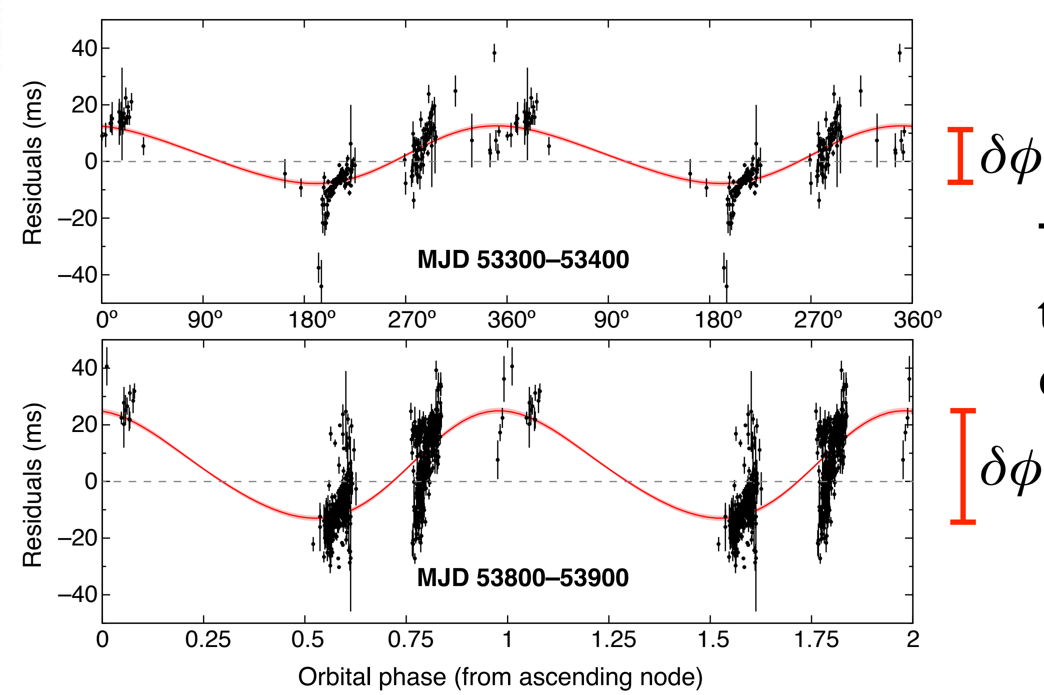
The harmonic drifts across the orbit can be explained with a simple radial-wind model:

$$\boldsymbol{w} = \frac{w_0}{r_{\mathrm{AB}}^2}\hat{\boldsymbol{r}}_{\mathrm{AB}}$$





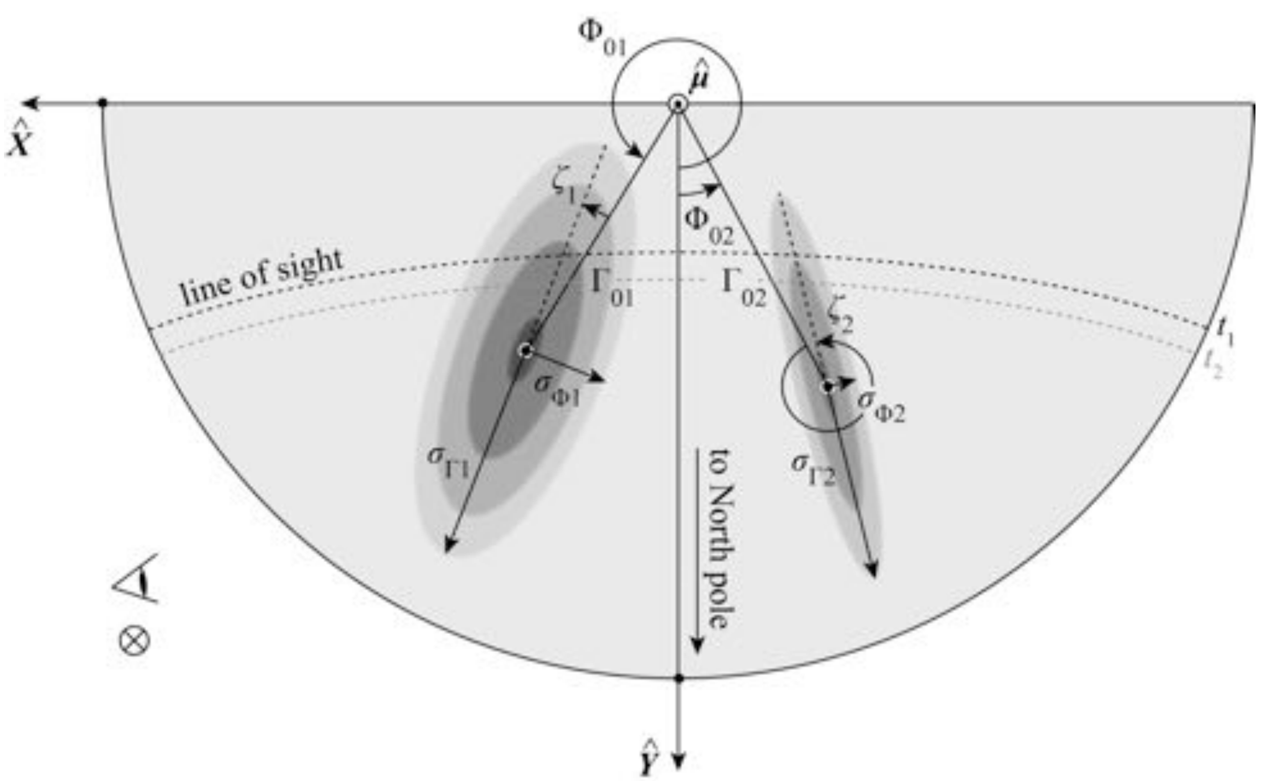
Impact angle between the wind and the beam direction (when observed) **changes due to geodetic precession**

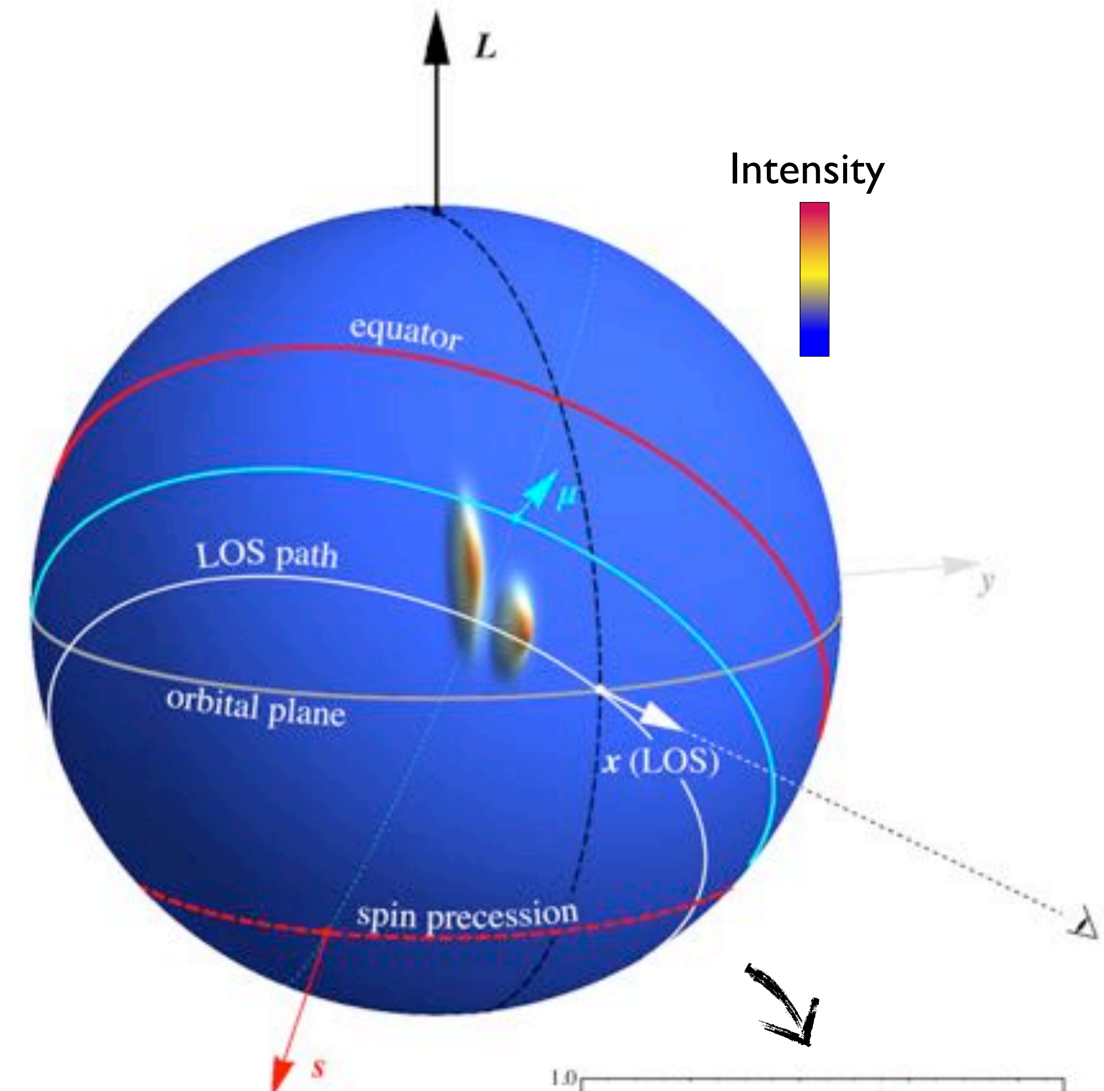


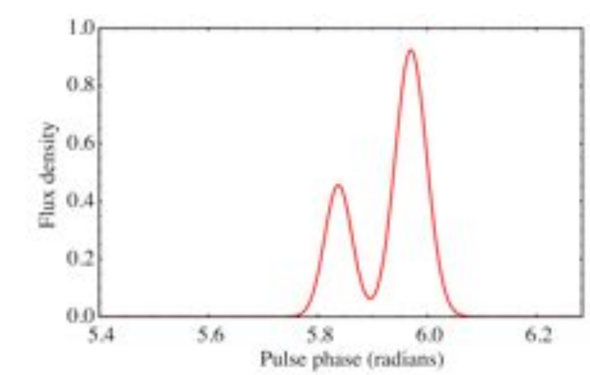
The magnitude of the phase delay changes as a result

Beam Model

Our parametrisation of the beam is a two-component Gaussian-surface beam model:







The spin and magnetic-field orientation, and the precession rate of Pulsar B were adopted from Breton et al. (2008):

$\alpha = 7\overset{\circ}{.}92$

$\theta = 130\overset{\circ}{.}02$

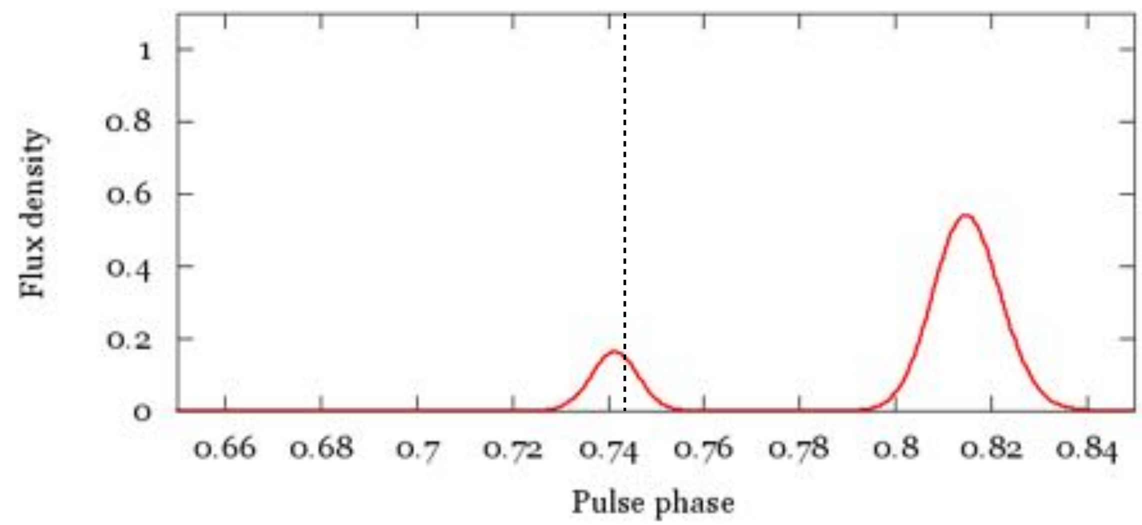
$\phi_{\rm SO}(\mathrm{MJD}\,53857) = 308\overset{\circ}{.}79$

$\Omega_{\rm SO} = 4\overset{\circ}{.}77\ \mathrm{yr}^{-1}$

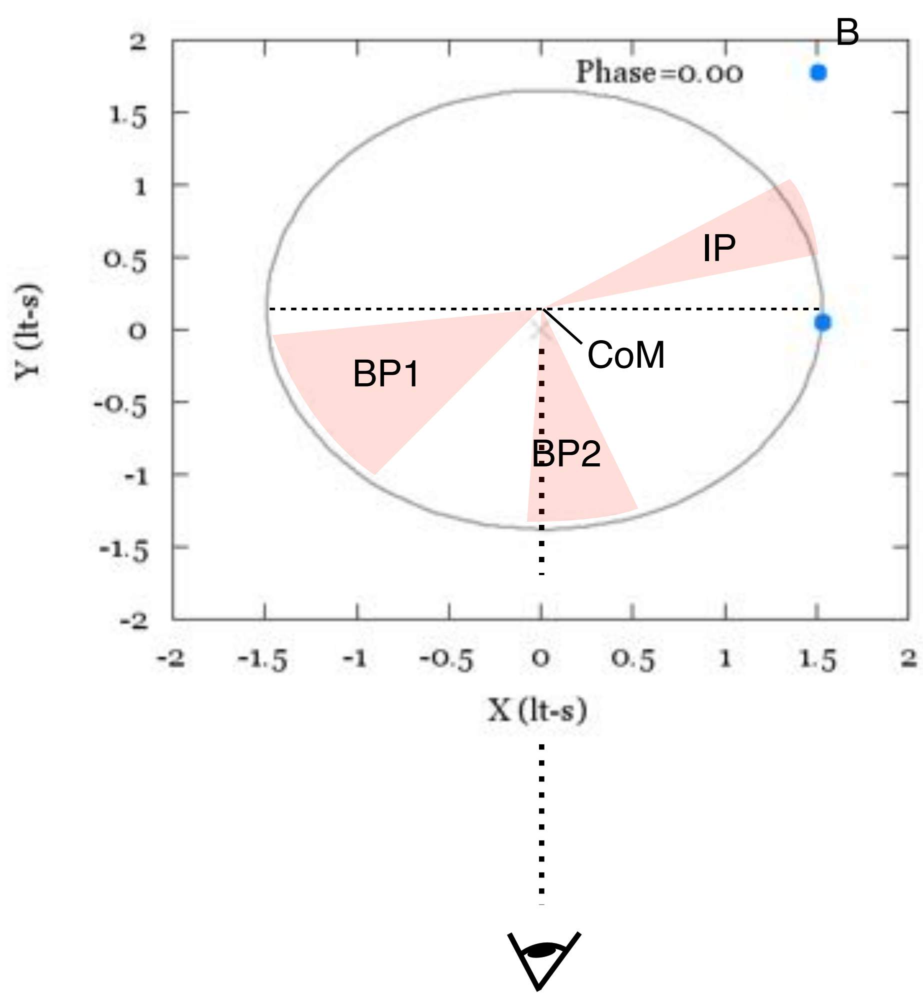
For a given set of model parameters and epoch, **our model generates a flux density profile:**

$$F(t) = f(t; I^J_{0\ell}, \Gamma_{0\ell}, \Phi_{0\ell}, \sigma_{\Gamma\ell}, f_\ell, \zeta_\ell, w_0)$$

Orbital Profile Evolution (20% wind)



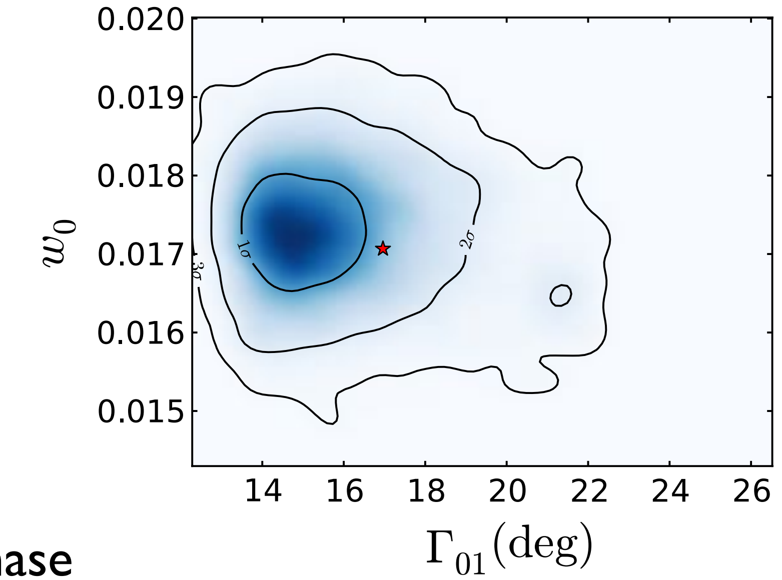
Profile evolution from our model, at a given epoch, across the orbit



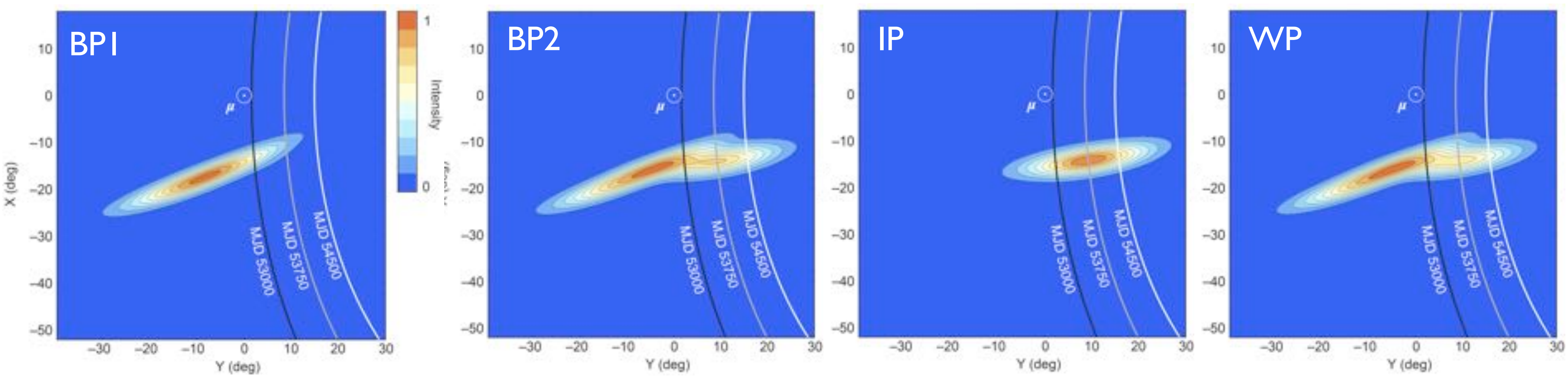
Model Parameter Estimation

$$\chi^2 = \sum_{i=1}^{N_{\rm profiles}} \left[\frac{F_i^{\rm obs} - F(t_i; I_{0\ell}^J, \Gamma_{0\ell}, \Phi_{0\ell}, \sigma_{\Gamma\ell}, f_\ell, \zeta_\ell, w_0)}{\sigma_i} \right]^2$$

→ POLYCHORD →

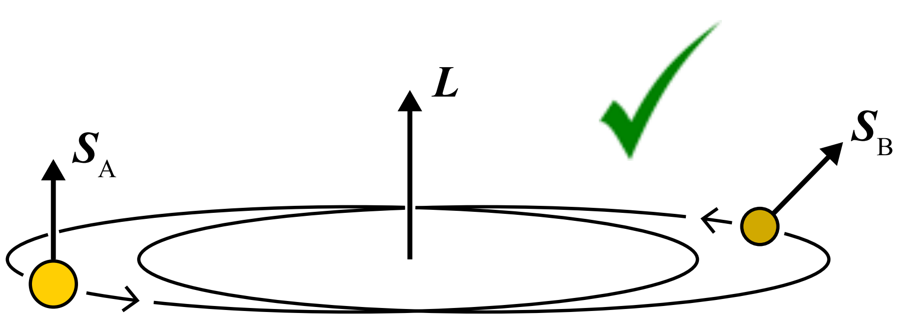


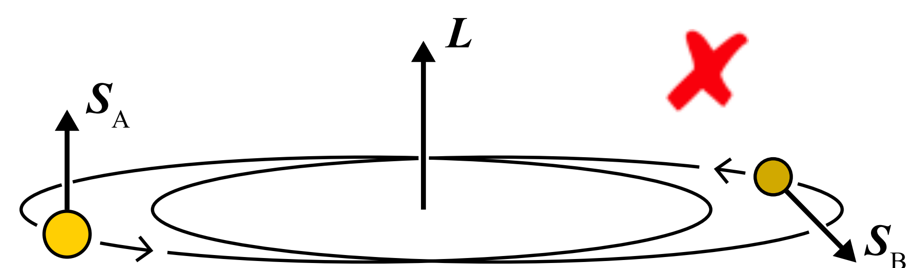
Relative intensity of the two Gaussian components as a function of orbital phase



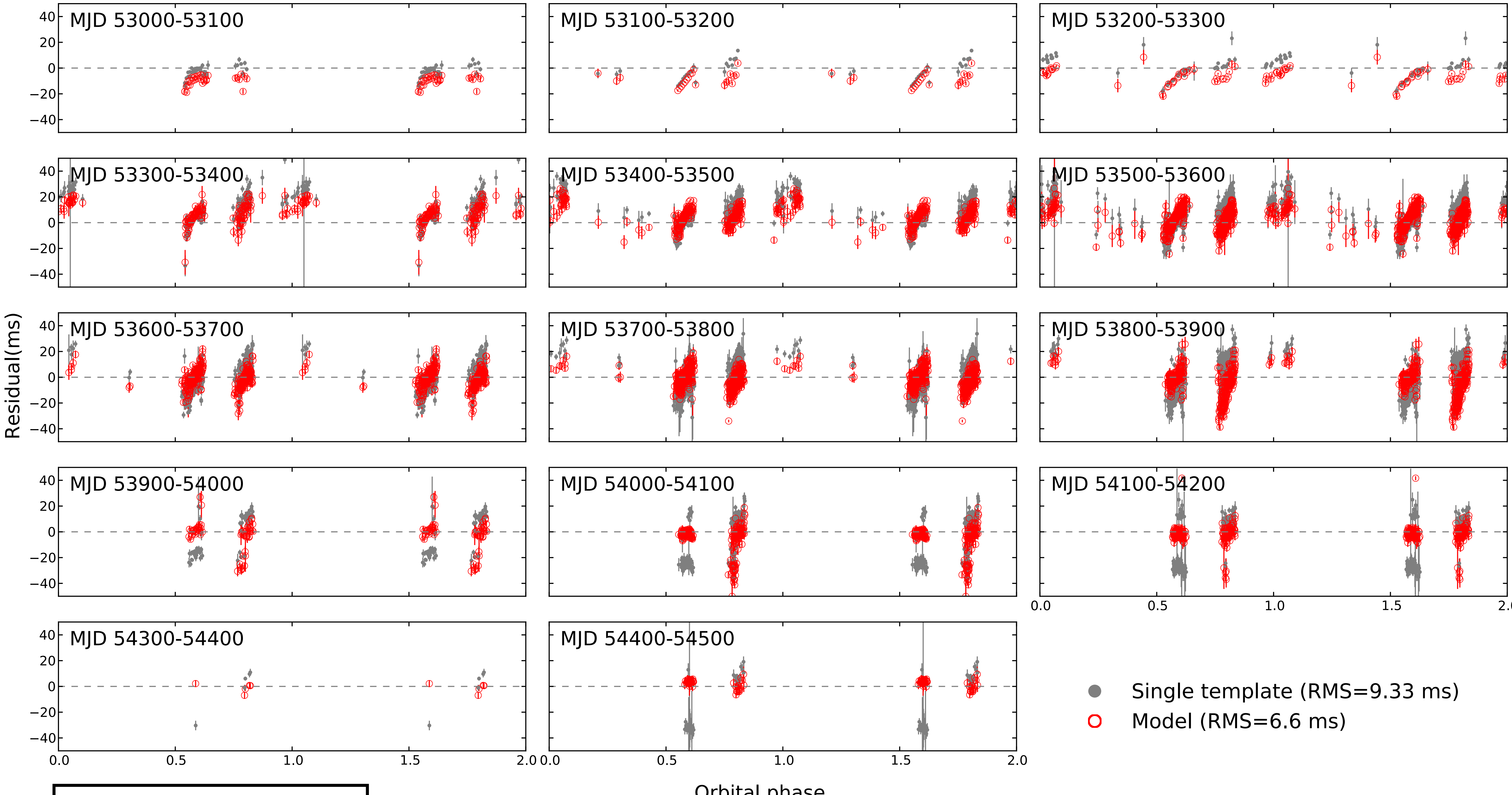
The most-likely, orbit-averaged beam deflection by the **wind** was **1.7% (of the emission height)**

The most likely configuration of **Pulsar B's spin is 'prograde'** w.r.t. the orbit (compatible with evolutionary arguments)





Timing Pulsar B with our Model



$$\sigma_{x_\mathrm{B}}^{\mathrm{model}} \approx \frac{1}{3} \times \sigma_{x_\mathrm{B}}^{2006}$$

Smaller effects, such as beam aberration, are still out of reach, with $\sigma_{x_\mathrm{B}}^{\mathrm{model}} \approx 2 \times \epsilon_\mathrm{A} x_\mathrm{B}^{\mathrm{int}}$

Caveat A! The above number does not consider co-variances between timing & model parameters

Caveat B! Without continuing timing upon Pulsar B's return, this work cannot be used for tests of GR

Summary & Conclusions

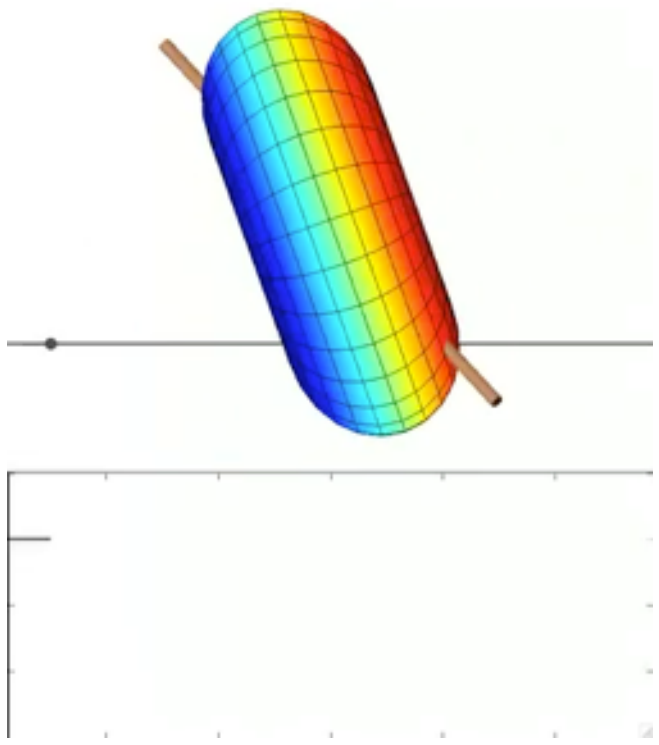
- We have modelled the harmonic drifts of Pulsar B's residuals with a 'wind-action' + beam model that harmonically displaces the pulsar beam along the orbit
- The most likely configuration is consistent with a wind parameter of 1.7% and a prograde spin.
- In the idealised case of zero-covariance, our model offers a 3-fold improvement in the measurement of *R*

Future

- Our modelling presents a significant improvement over previous work, **BUT** there are **significant, unmodelled components** in our timing

  A model describing this interaction is needed to achieve sub–4 ms RMS

- When pulsar B inevitably becomes visible again (ca. 2024; Breton 2009), it will be possible to perform **joint timing** between pulsars A and B, and further **increase the precision of the observed timing parameters**



- Finally, If coherent timing is achieved, it will provide a long timing baseline which can be used in precise tests of GR via the Ω_{SO} parameter, in models such as the eclipse model of Breton et al. (2008)

Publication: Noutsos et al. in prep. (to be submitted soon)