Pulse variations in XTE J1814-338

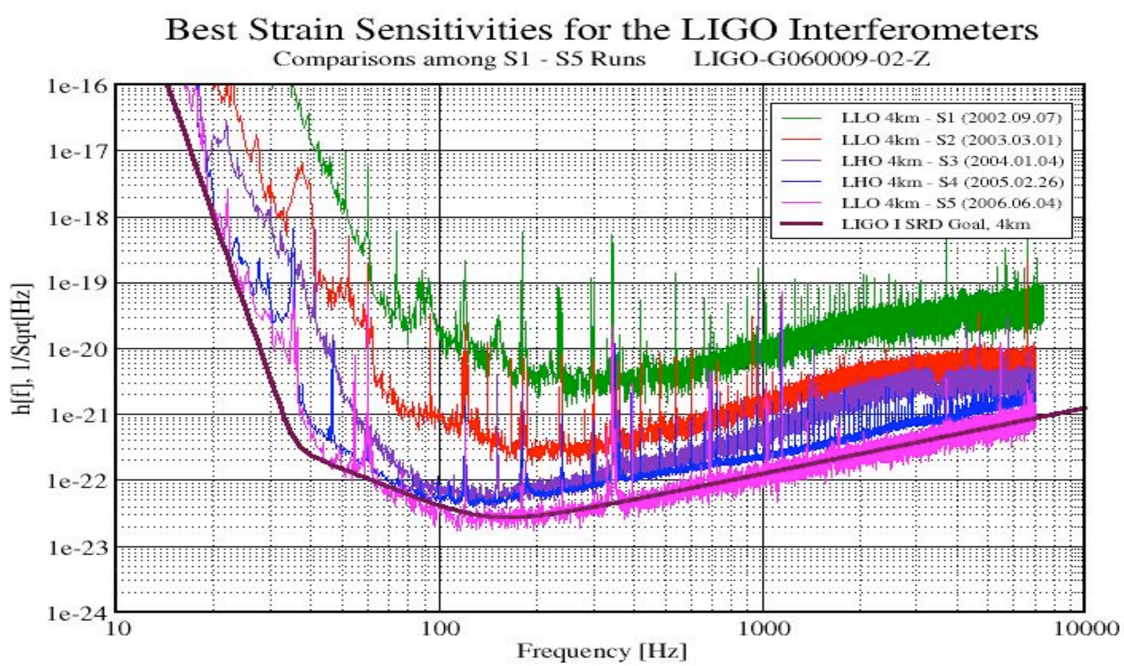
Christine Chung, Duncan Galloway, Andrew Melatos

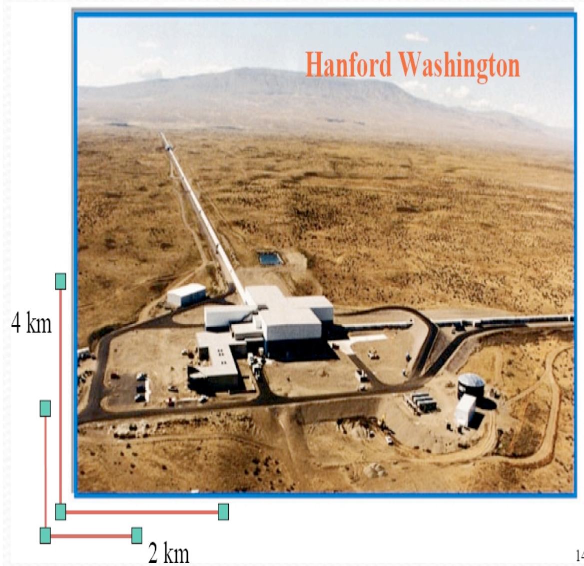
A Source of Gravitational Waves

- According to most NS equations of state, the breakup frequency of a pulsar is ~1500 Hz.
- The fastest known MSP is spinning at 716 Hz.
- This discrepancy is thought to be due to torque from gravitational radiation balancing the accretion torque, preventing the pulsar from spinning at > 1000 Hz.
- Potential sources of gravitational radiation: magnetic mountains, glitches, precession?

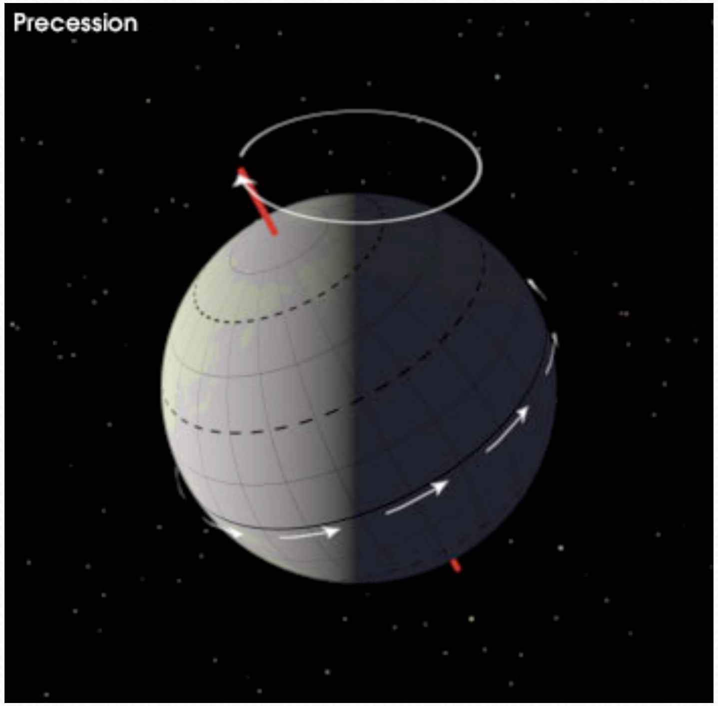
Gravitational Wave Detection

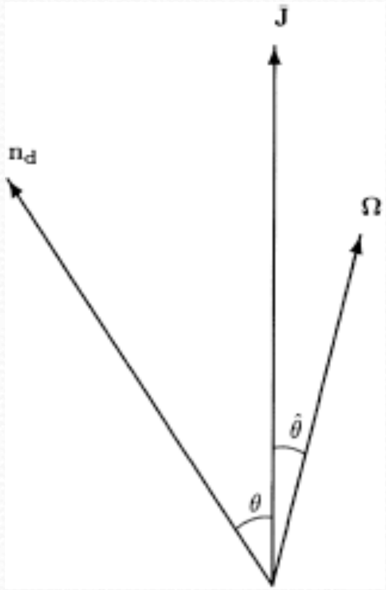
- Sources:
  - Transient (mergers, supernovae...)
  - Persistent (early universe, binaries, pulsars...)
- LIGO to detect high frequency sources (>1 Hz)
- AMSPs emit GW at 1x and 2x spin frequency (~1000 Hz)





Precession: Theory





Two rotations:

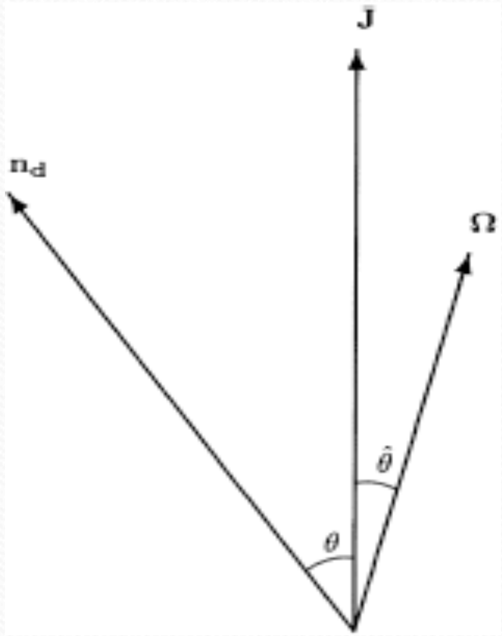
1. Symmetry axis n_d rotates about angular momentum vector J rapidly (rotation frequency Ω_r)

2. Body of pulsar rotates about n_d slowly (precession frequency Ω_p)

Image from http://earthobservatory.nasa.gov/Library/Giants/Milankovitch/milankovitch_2.html

Precession: Effects

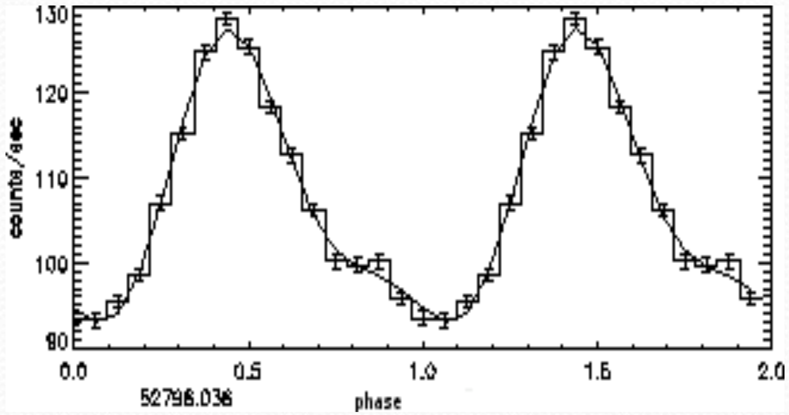
- Modulation of the phase and intensity on the timescale of the precession period
- Previously predicted analytically for radio pulsars by Jones & Andersson (2002)
- $\varepsilon = \Omega_p / \Omega \cos \theta$
  - ε = ellipticity
  - Ω_p = precession frequency
  - Ω = total rotation frequency
  - θ = tilt angle

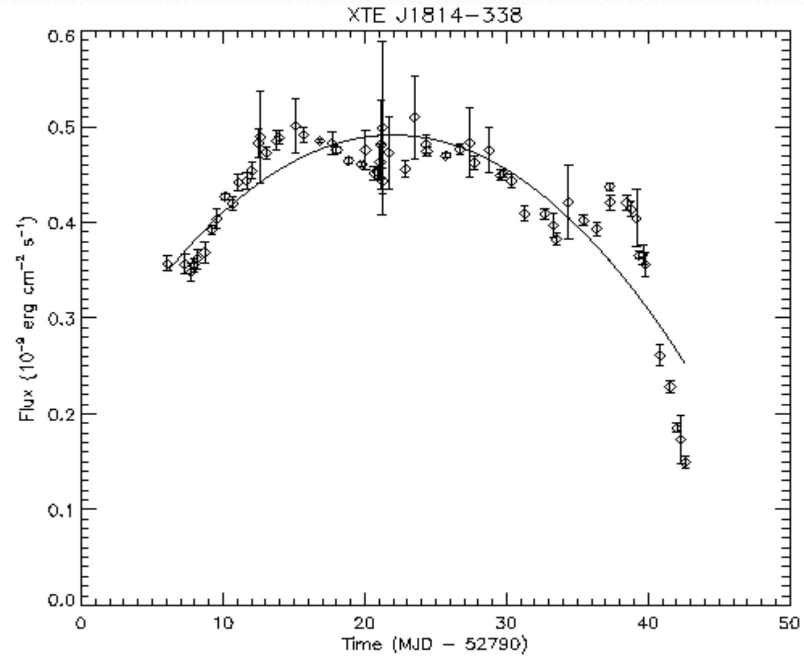


Data reduction: J1814–338

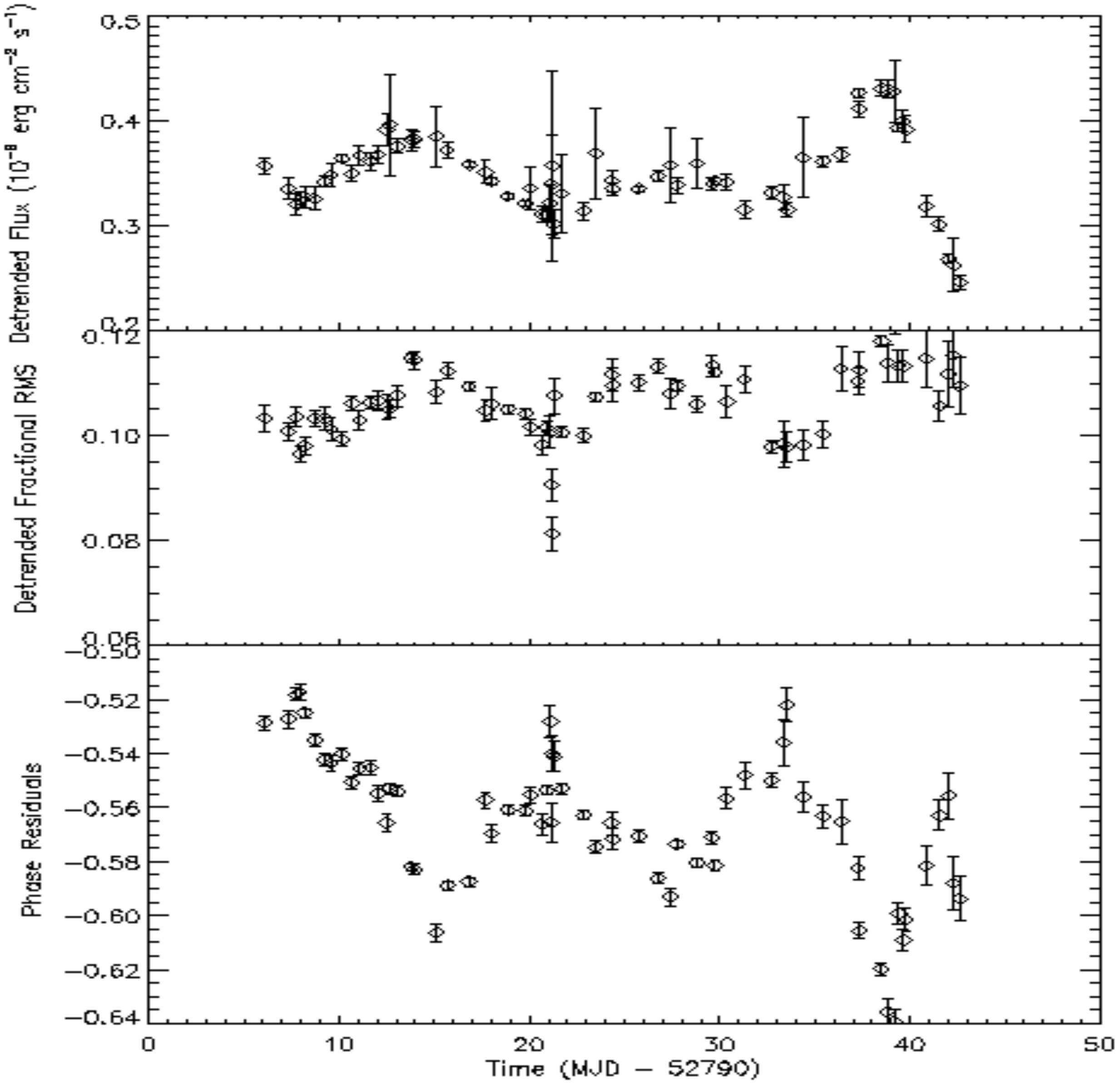
- Barycentre & satellite orbit correction
- Background subtraction, removal of any Type 1 bursts in data
- Fold over spin period (~0.003s) to get pulse profiles
- Fit profiles with fundamental & first harmonic components:

$A + B \sin(2\pi\theta + C) + D \sin(4\pi\theta + E)$





Data reduction: flux, rms & phase residuals

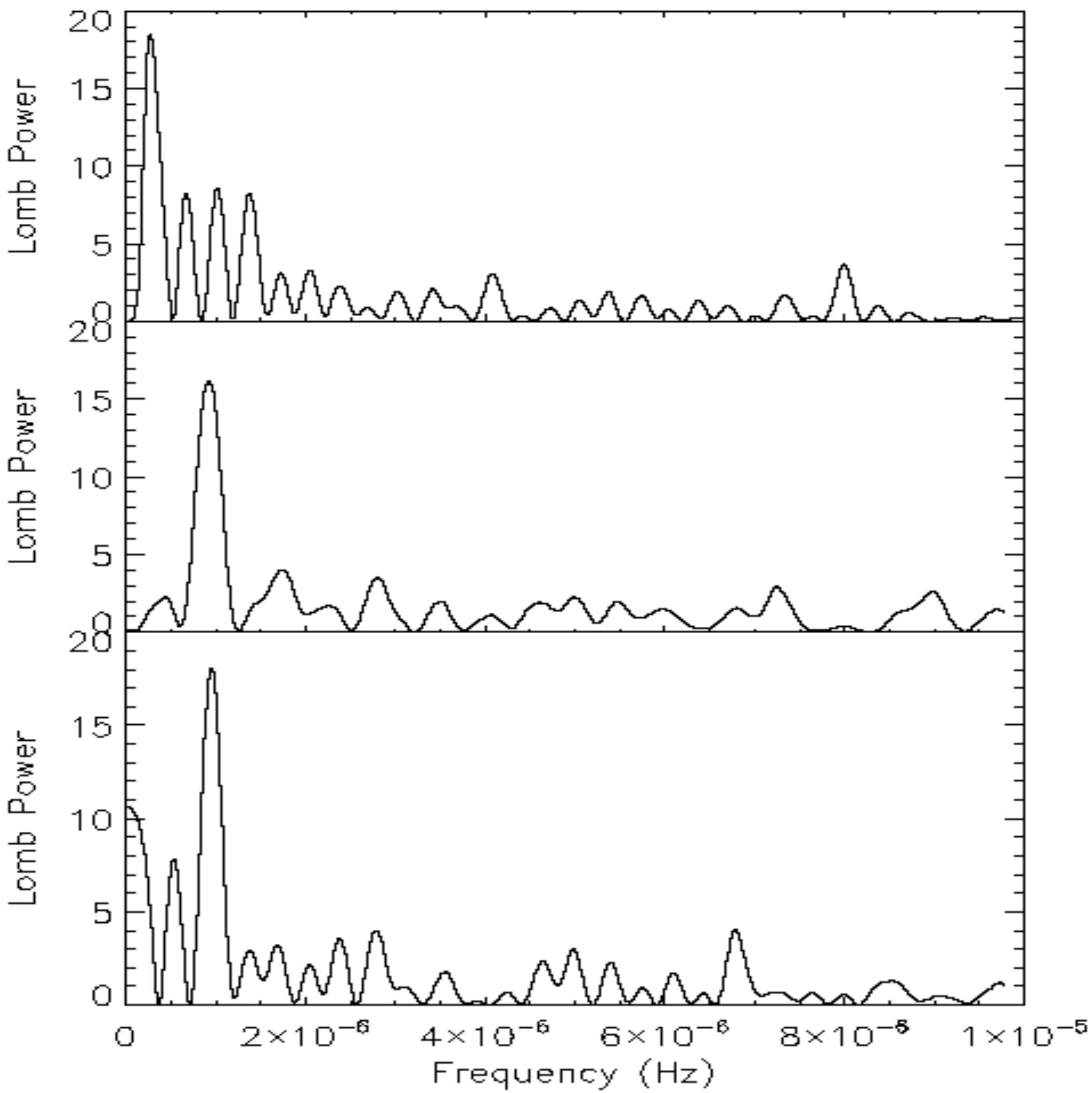


Flux

Fractional rms
B/sqrt(2) A

Phase residuals
0.25 – C/(2π)

Lomb periodogram



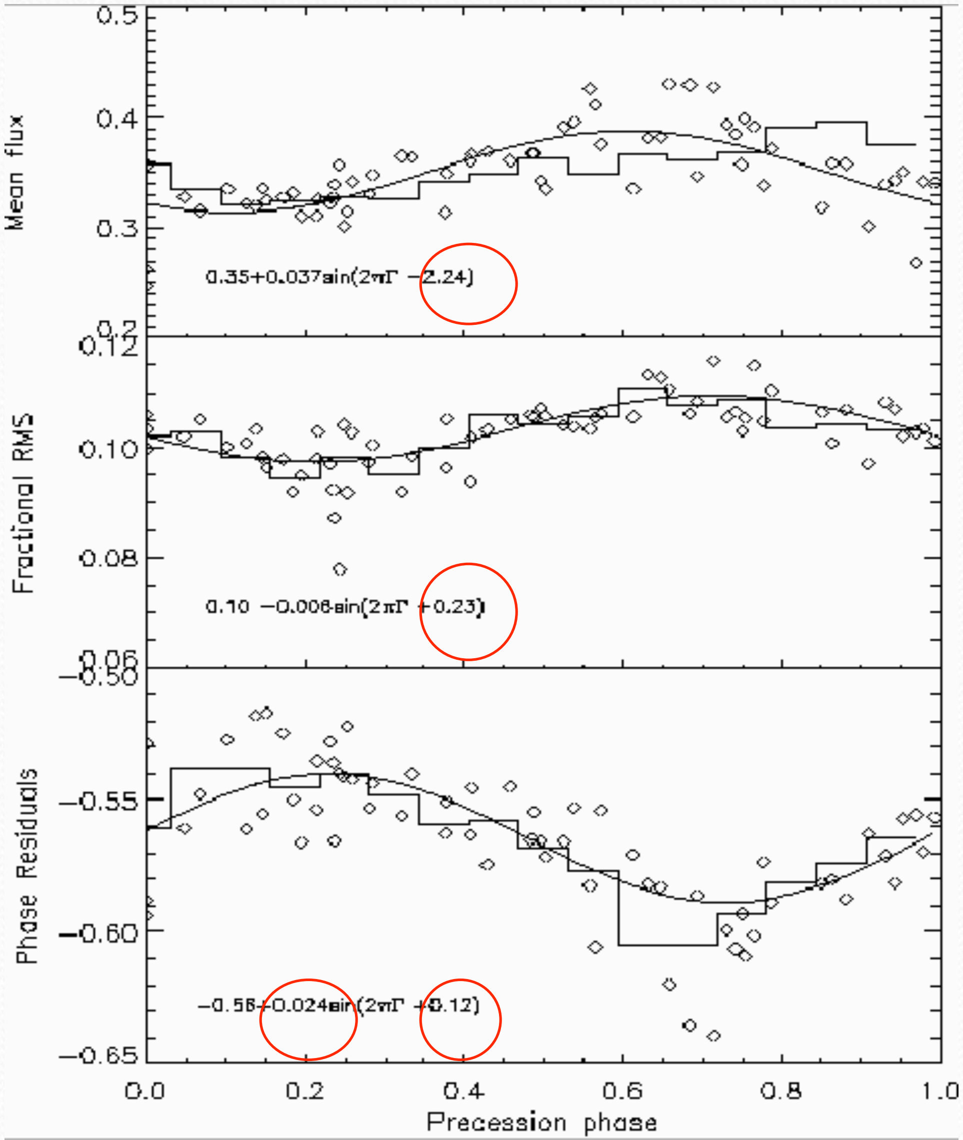
Flux period:
11.8 ± 0.8 days

RMS period:
12.6 ± 0.8 days

Phase residual period:
12.2 ± 0.8 days

Mean period:
12.2 ± 1.3 days

Final result



- Phase residuals, RMS and flux are folded over the mean period, then fitted with
- $A + A_m \sin(2\pi\Gamma + \Phi)$
- Compare the following measured quantities to simulations:

Phase residual-RMS precession phase offset, $\Delta\varphi_{phase}$ = 3.1 ± 0.2

Flux-RMS precession phase offset, $\Delta\varphi_{flux}$ = 0.7 ± 0.3

Phase residual amplitude, A_{phase} = 0.024 ± 0.003

Simulations: parameter search

- Precession period determined by θ and ε
- Fixed parameter: ε = 0.001
- Initial parameters: θ, φ, *i*, α (hotspot latitude)
- Vary these 4 parameters in search of a match to the three data values of $\Delta\Phi_{phase} = 3.01$, $\Delta\Phi_{flux} = 0.7$, $A_{phase} = 0.024$
- Generally:

  θ determines phase amplitude A_{phase}

  i, α, (φ) determines precession phase offsets ΔΦ

Simulations: parameter search

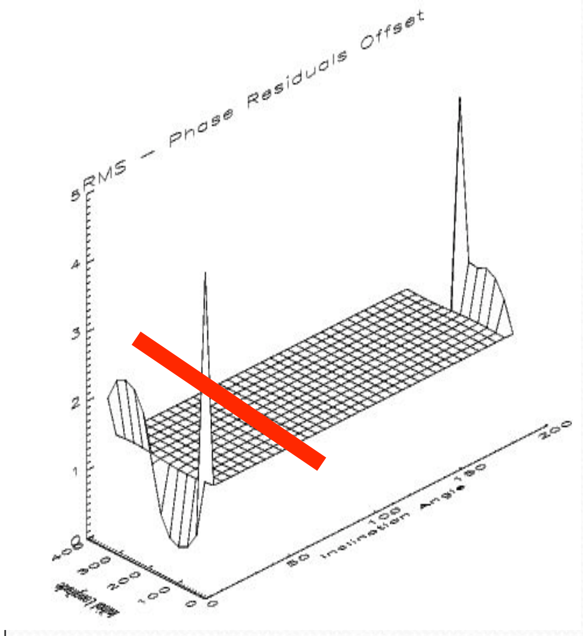
- For most configurations of i, φ we find

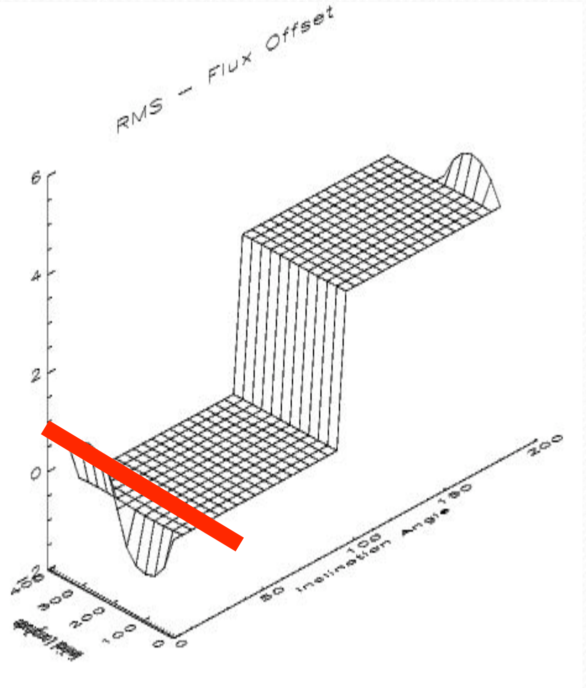
  $\Delta\varphi_{phase} \sim \pi/2$

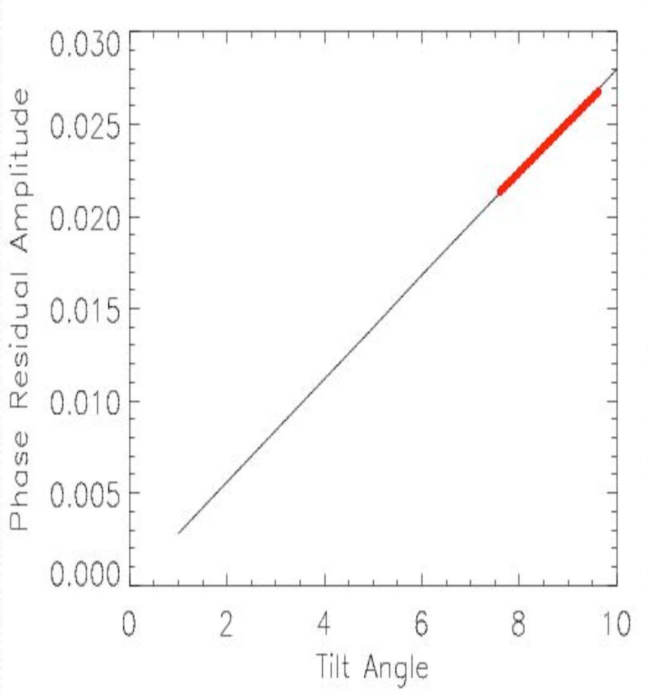
  $\Delta\varphi_{flux} \sim \pi$ (if hotspot is in same hemisphere as LOS)

  ~ 0 (if hotspot is in different hemisphere as LOS)

- A_{phase} increases with Θ (~ 0.024 for Θ = 9°)







Is there a match?

- Near match for $\Delta\varphi_{phase}$, $\Delta\varphi_{flux}$ only for $i < 1°$
- The likelihood of us seeing a pulsar with such a small inclination angle i is almost zero, assuming isotropic distribution of pulsars.
- Such a small i means that the fractional RMS that we'd see is also tiny, i.e. < 1% (but the data shows ~10% RMS)
- So, either:
    - Our model is too simple (inaccurate surface map)
    - The source is not really precessing.

In summary…

- Reduced and analysed X-ray timing data of 3 AMSPs in hopes of finding evidence of free precession
- Possible signal in J1814-338
- Performed simulations, and found results matching the data only in the most unlikely configuration
- Howeve, we can estimate upper limits:
  - $\varepsilon \sim 10^{-9}$, $5 < \theta < 10$ (inaccurate surface map)
  - $\varepsilon \cos \theta < 10^{-10}$ (no precession)