Periodic modulations and a glitch in PSR B1828-11

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Planets around pulsars

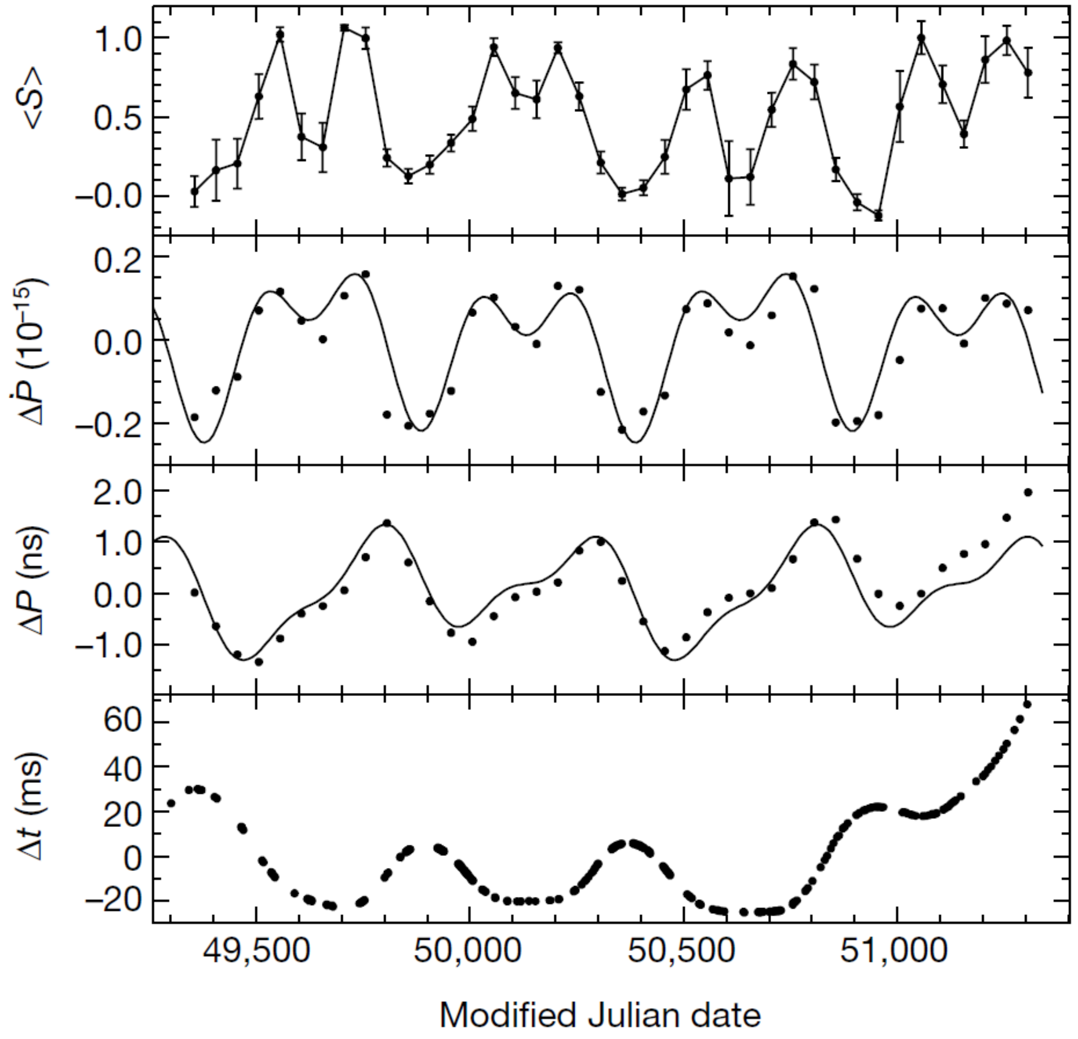
- Bailes, Lyne, & Shemar (1993) *"Limits on pulsar planetary systems from the Jodrell bank timing database"*, ASP Conf. Ser. 36:

PSR 1828–11

Young pulsars with large period derivatives often exhibit large amounts of timing noise. One of the young pulsars from the Clifton and Lyne survey was PSR 1828–11. This pulsar has a period of 405 ms and a $\dot{P}$ of ~60. Although the residuals for this pulsar can be modelled by two sinusoids with periods of 492 and 1043 days, and amplitudes of 13 and 22 milliseconds respectively, the model fitted to the data presented at the conference failed to correctly predict the arrival times of more recent data without the inclusion of a substantial period second derivative. Whilst we shall continue to monitor this pulsar in the future, until the model can accurately predict pulse arrival times, a planetary interpretation must be greeted with some caution, especially considering the large period derivative of the pulsar.

Precession

- [Stairs, Lyne, Shemar (2000), Nature, *"Evidence for free precession in a pulsar"*]
- $\langle S \rangle$ is a measure of pulse shape
- Distinctive double-peak in spindown rate
- Precession naturally predicts both the time-scale and form of modulations



Ruling out a planetary hypothesis

- Correlated changes in spindown and pulse shape would require planets to interact with the magnetosphere
- Separation of planet and star is about 1 AU
- Light-cylinder radius $\sim c \times P \approx 10^{-3}\ \mathrm{AU}$
- Difficult to see theoretically how a planet could interact with the magnetosphere
- Additionally a single planet does not produce the 2 harmonically related timing corrections. (Perhaps 2 planets in resonant orbits)

Precession

- Precession is a purely geometric effect which occurs in non-spherical bodies where the spin-vector is misaligned with the angular momentum.
- The free-precession period is given by

$$P_{\text{fp}} \approx \frac{P}{\epsilon}$$

- Here ϵ is the biaxial deformation. For ~ 500 day precession period and $P = 0.405$s, then $\epsilon \sim 10^{-8}$

Implications of precession

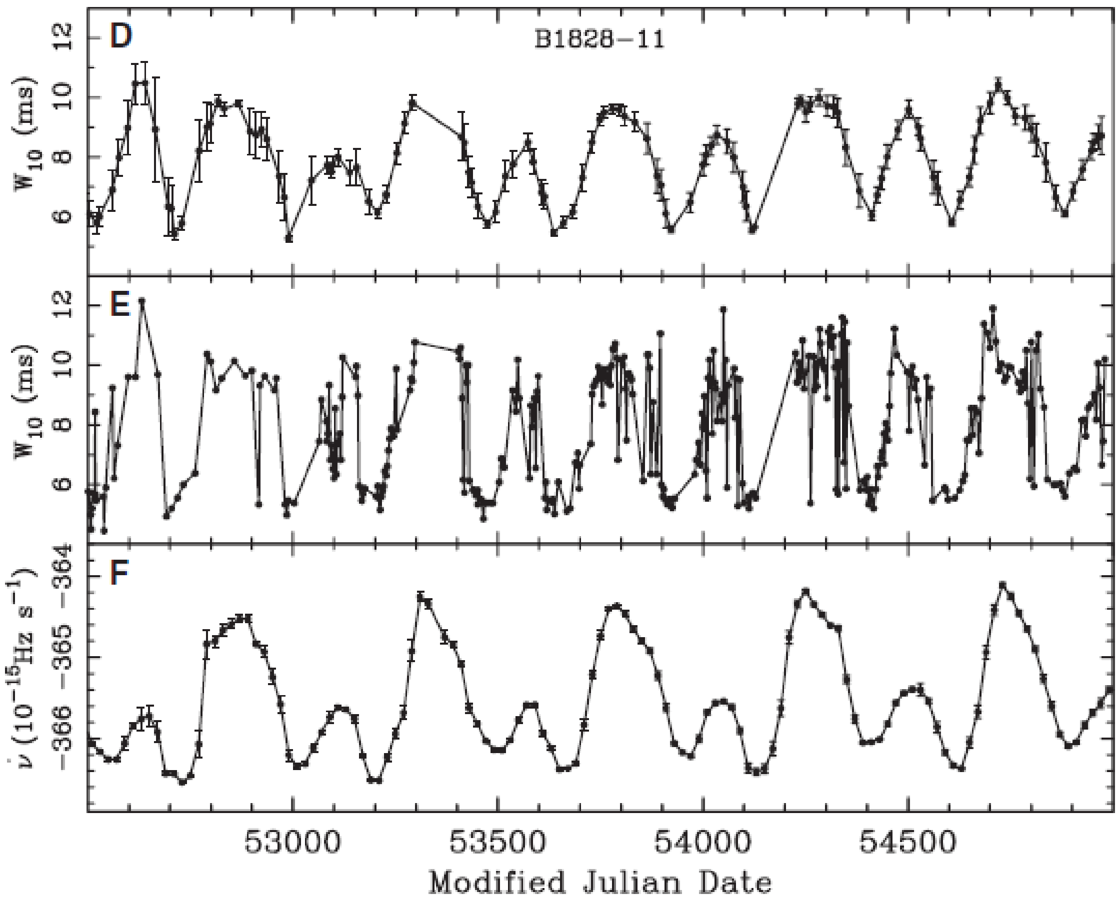
- The fact we don't commonly see it in pulsars indicates it is somehow suppressed
- Perhaps $\epsilon \ll 10^{-8}$ for most pulsars (see, e.g., Biryukov, Beskin, Karpov (2012))
- Shaham (1977) suggests this is due to "vortex pinning"
  - Pulsar glitches suggest the presence of a pinned vortices in neutron stars
  - The fraction of pinned superfluid required to explain glitches is
$$\frac{I_p}{I_0} \sim 10^{-3}$$
  - If there is a pinned superfluid then $P_{\mathrm{fp}} \sim \frac{I_p}{I} P$
  - Inconsistent with observations of precession in PSR B1828-11

The story before 2010

- PSR B1828-11 believed to be demonstrating precession (but not glitching)
- Many other pulsars glitching believed to be due to vortex unpinning
- These two models are inconsistent
- See e.g. Jones & Andersson (2001) for a review of precession and implications for glitches

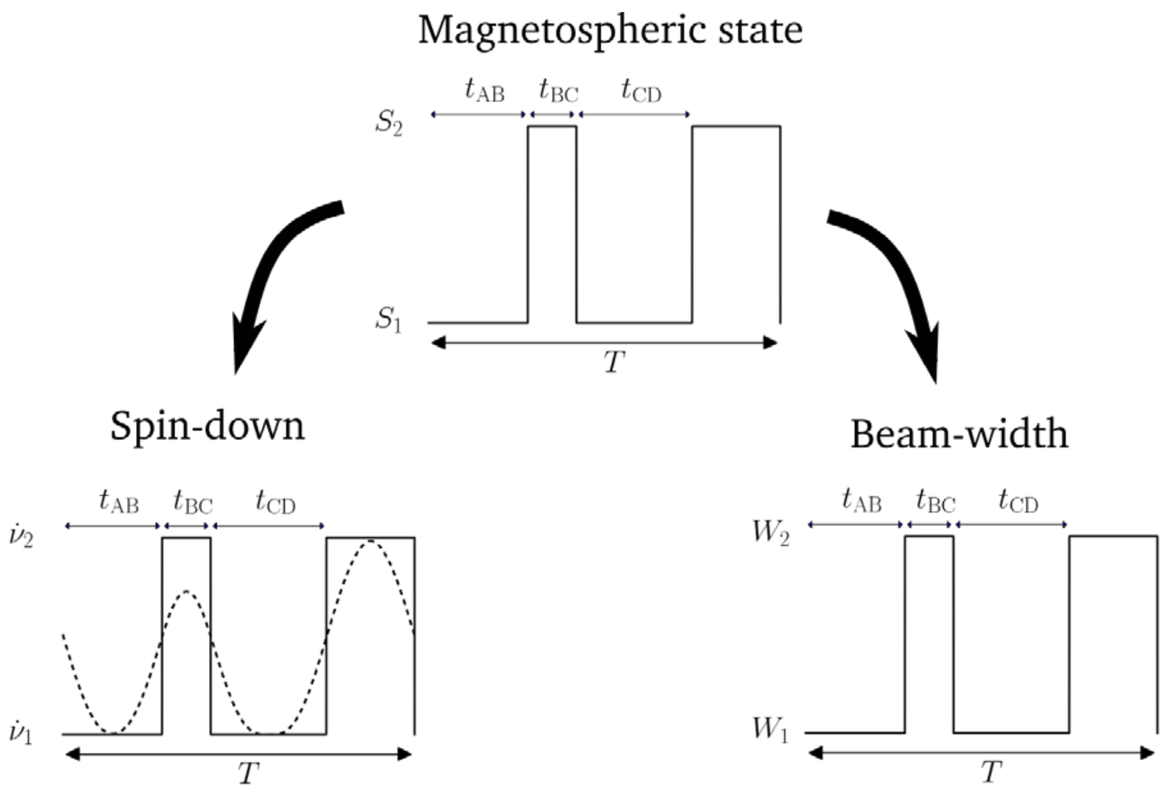
2010 Magnetospheric switching

- [Lyne et. al. (2010) “Switched magnetospheric regulation of spin-down”]
- Motivated by B1931+24 (the intermittent pulsar)
- Proposed quasi-periodic behaviour is due to switching between magnetospheric states



Quantitative model

- Perera et al. (2015) "Correlated spin-down rates and radio emission in PSR B1859+07"
- The double-peaked spin-down requires four states
- Time-averaging explains the "smooth" behaviour of the spin-down



Magnetospheric switching

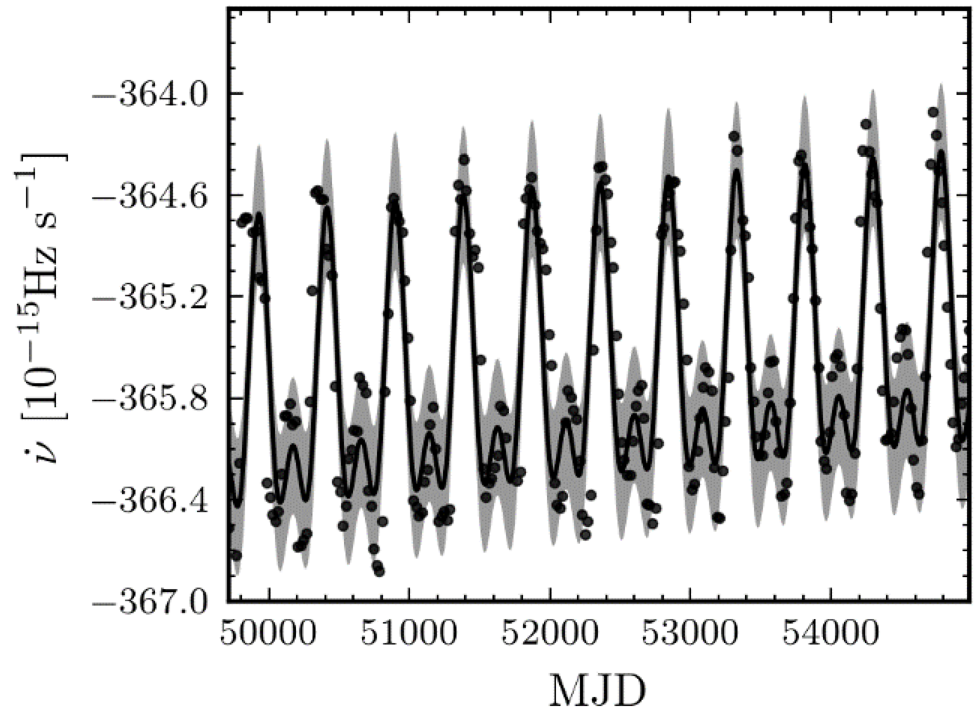
- Physical model requires further development
- No obvious “clock” to regulate the switching
- Clock needs four discreet repeating states
- Suggestion by Jones (2012) “Pulsar state switching, timing noise and free precession”

Short and long switching

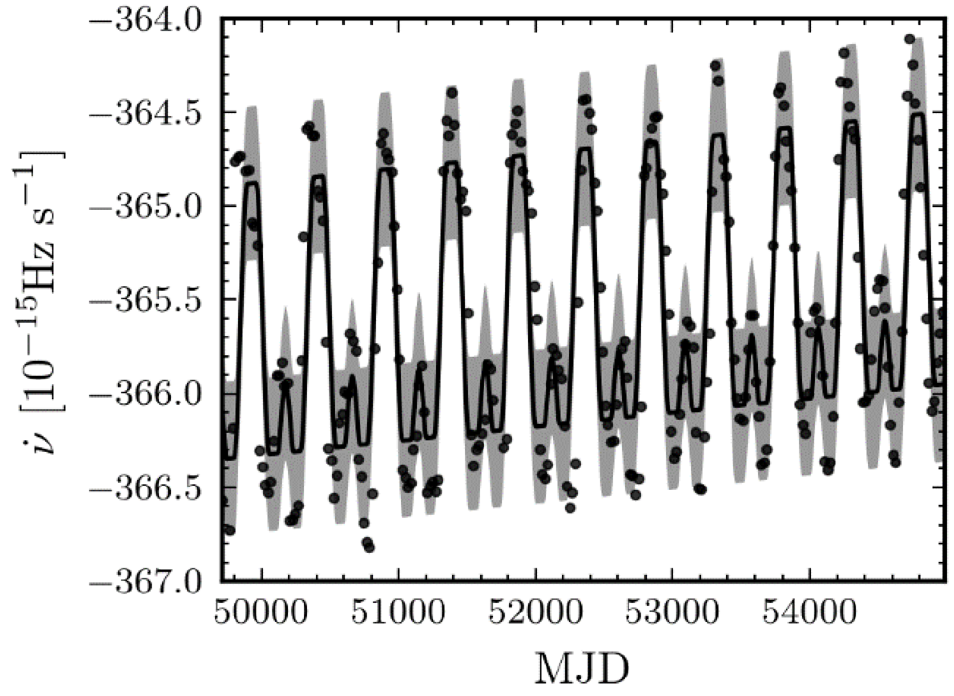
- Pulsar clearly demonstrates two distinct pulse shapes
- Stairs et al. (2003) "High-resolution observations of PSR B1828-11"
  - Suggest the clock biases which state it is in (as opposed to a deterministic switch)
- Akgun, Link, and, Wasserman (2006) demonstrates this could nevertheless still be consistent with precession (patchy beams)

Comparing switching and precession: spindown

Precession : Maximum posterior fit + 1-sigma



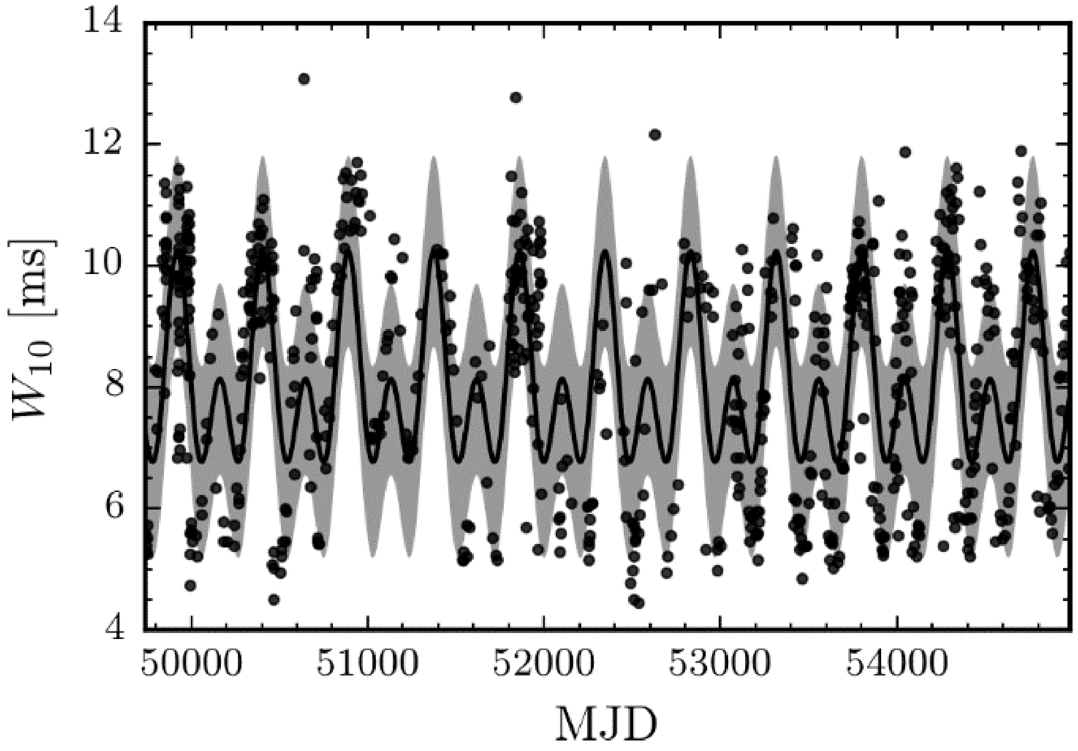
Switching : Maximum posterior fit + 1-sigma



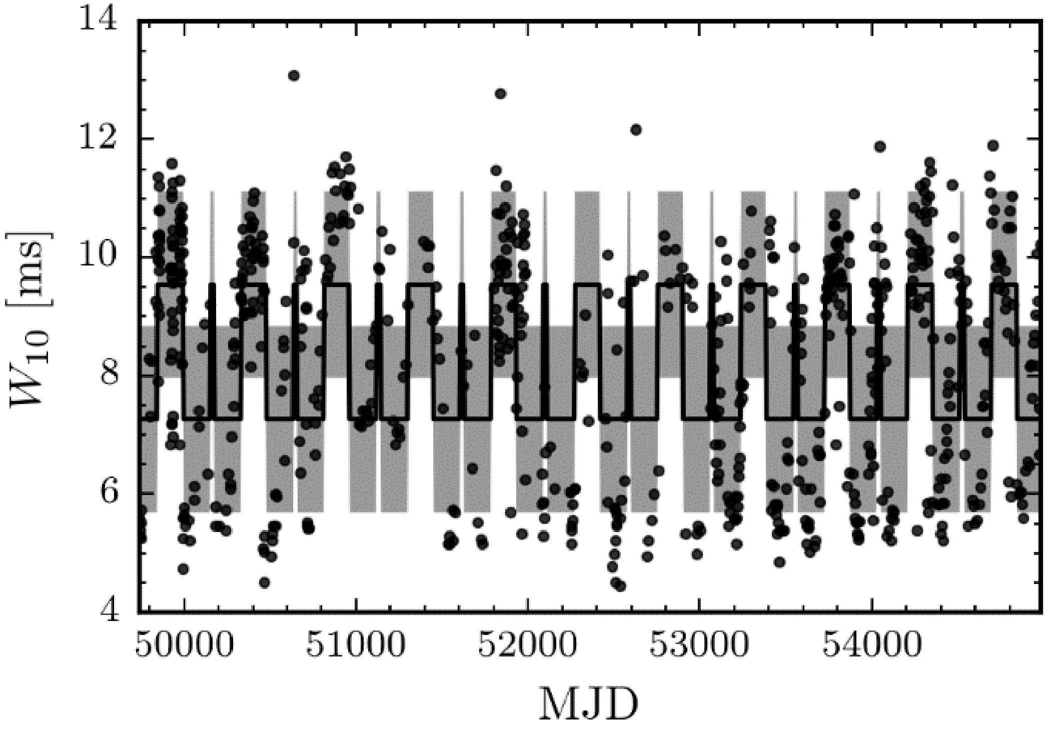
Results from Ashton, Jones, Prix (2016) data courtesy of Andrew Lyne

Comparing switching and precession: beamwidth

Precession : Maximum posterior fit + 1-sigma



Switching : Maximum posterior fit + 1-sigma



Results from [Ashton, Jones, Prix (2016)](#) data courtesy of Andrew Lyne

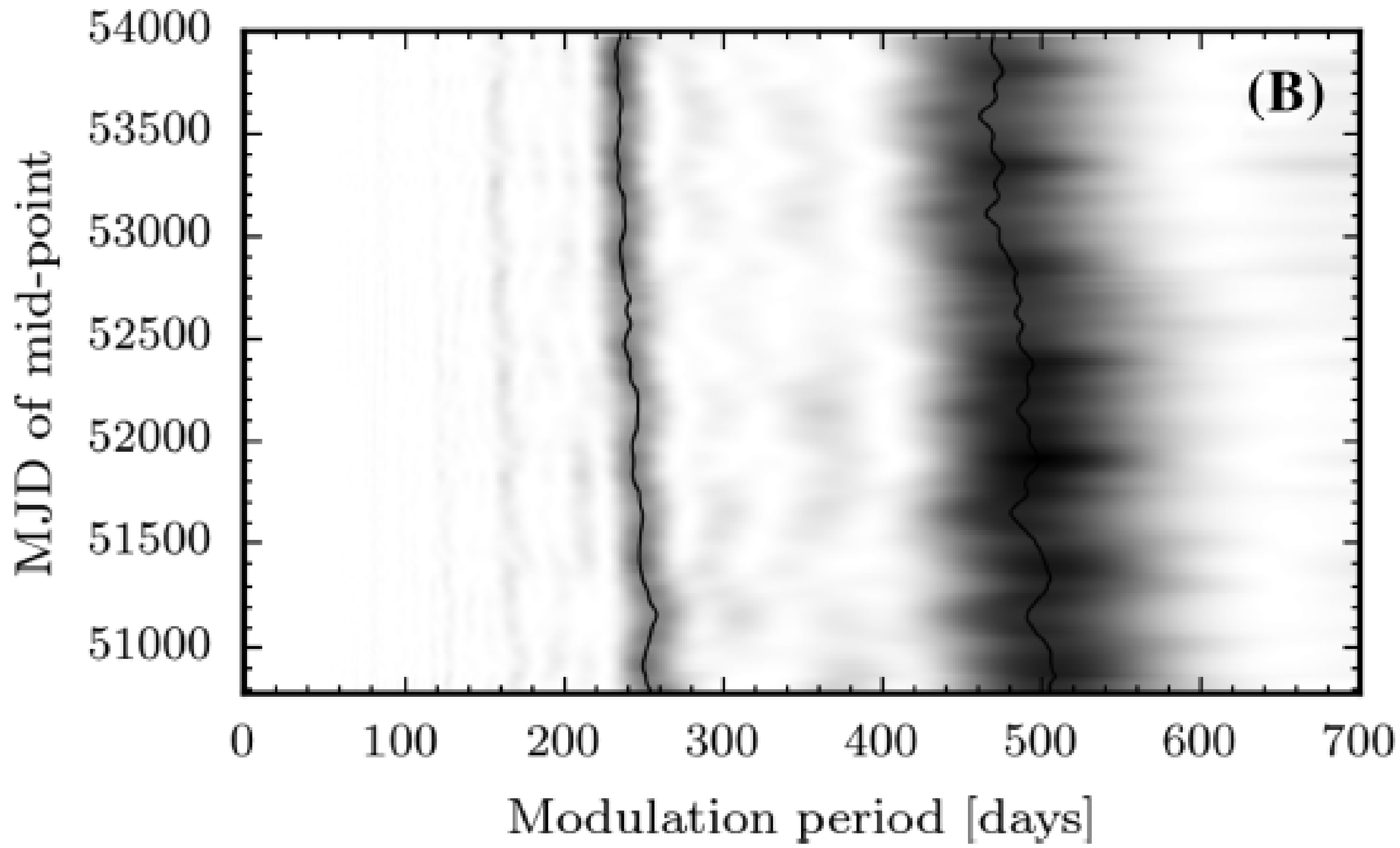
Comparing switching and precession

- Ashton, Jones, Prix (2016)
- Bayesian model comparison of switching and precession
- Careful work required to define priors
- Used spin-down data to inform priors for the beam-width
- Found an odds in support of precession (assuming equal prior-odds)

$$\frac{P(\text{ precession } | \text{ beamwidth data })}{P(\text{ switching } | \text{ beamwidth data })} = 10^{2.7 \pm 0.5}$$

A changing modulation period

- Ashton, Jones, Prix "On the free precession candidate PSR B1828–11: evidence for increasing deformation" (2017)
- Period changes from 505 to 470 days over 3200 days
- $\dot{P}_{\mathrm{mod}} \sim -0.01$



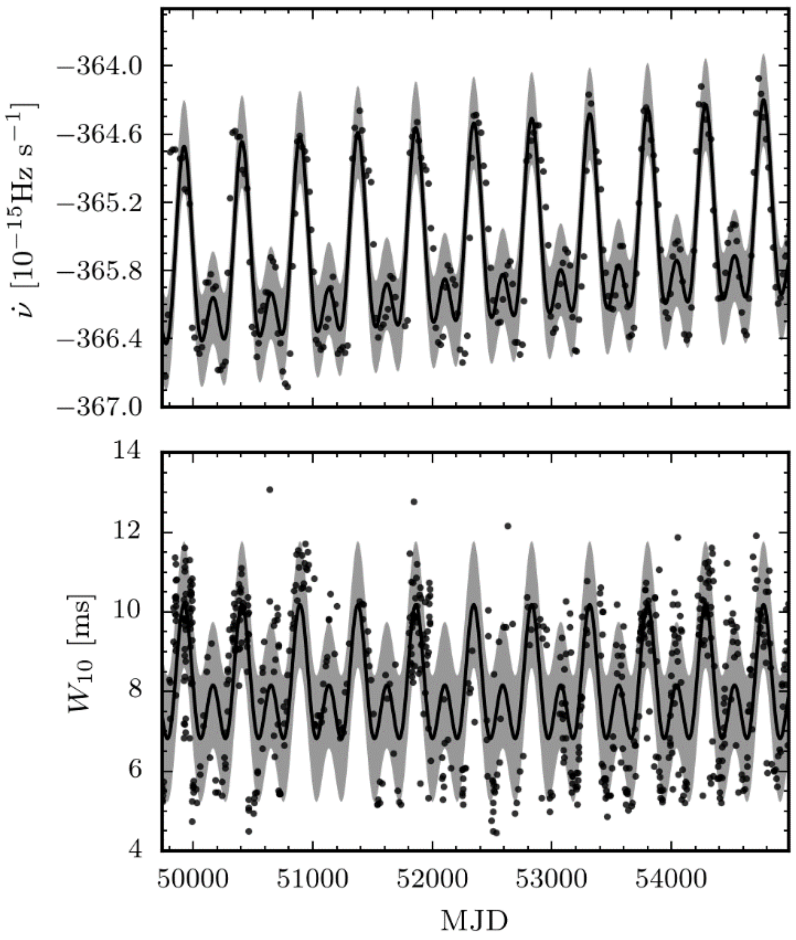
In the context of precession

- For the usual free precession model, $P_{\mathrm{fp}} = \frac{P}{\epsilon \cos\theta}$
- Can rule out variation in P due to spin-down: not large enough and makes the precession period longer not shorter
- Can rule out variation in θ as there is no corresponding change in the amplitude of modulations
- Left with a changing deformation, we model this by

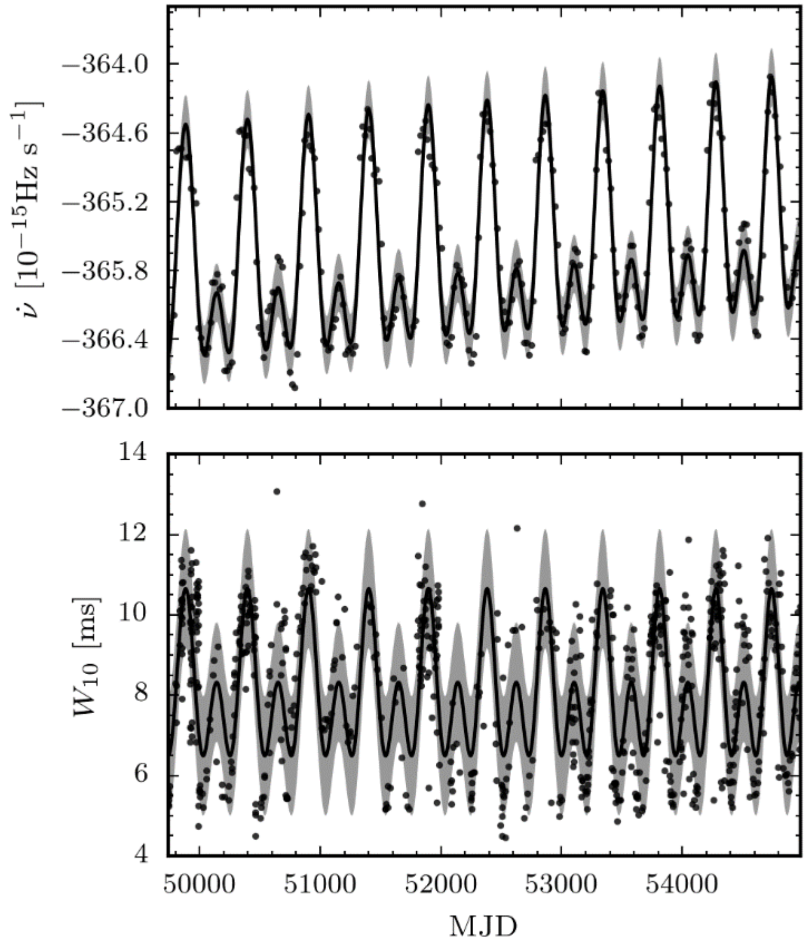
$$\epsilon(t) = \epsilon_0 + \dot{\epsilon}\,(t - t_0)$$

Comparing

The base-model (i.e. $\dot{\epsilon} = 0$)



Fitted model $\dot{\epsilon} \approx 10^{-18}\, 1/s$



Bayes factors

- Comparing the models quantitatively

$$\frac{P(\text{ precession with } \dot{\epsilon} \neq 0 \mid \text{ data })}{P(\text{ precession with } \dot{\epsilon} = 0 \mid \text{ data })} \approx 10^{74}$$

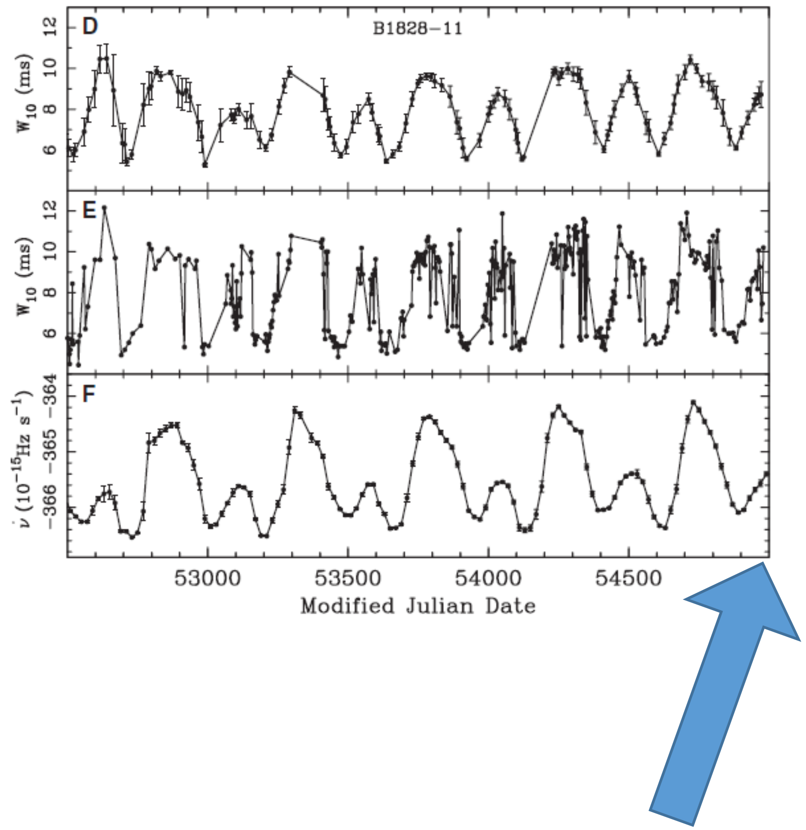
- This result roughly holds for any periodic model with a changing period

Interpretation

- The posterior value of $\dot{\epsilon} \approx 10^{-18}$ [1/s]
- This indicates the deformation is growing on a timescale of 200 yrs
- Difficult to understand theoretically
  - Accretion can be ruled out on the basis that the amount required would have a noticeable X-ray emission
  - Evolving magnetic field would require the internal field to change on a timescale of 400 years
  - Increase in superfluid pinning – again difficult to foresee why

PSR B1828-11 underwent a glitch

- Noted in the Jodrell Bank glitch catalogue (http://www.jb.man.ac.uk/pulsar/glitches/gTable.html)
- Glitch MJD 55041.75 coincides with the end of the Lyne et al (2010) data set
- $\frac{\delta\nu}{\nu} \approx 6 \times 10^{-9}$ $\frac{\delta\dot{\nu}}{\dot{\nu}} \approx 5 \times 10^{-3}$
- This isn't entirely unique. PSR B0919+06 (Perera et al. (2014)) also demonstrates periodic modulations and underwent a glitch



MJD of glitch

Implications of the glitch for precession

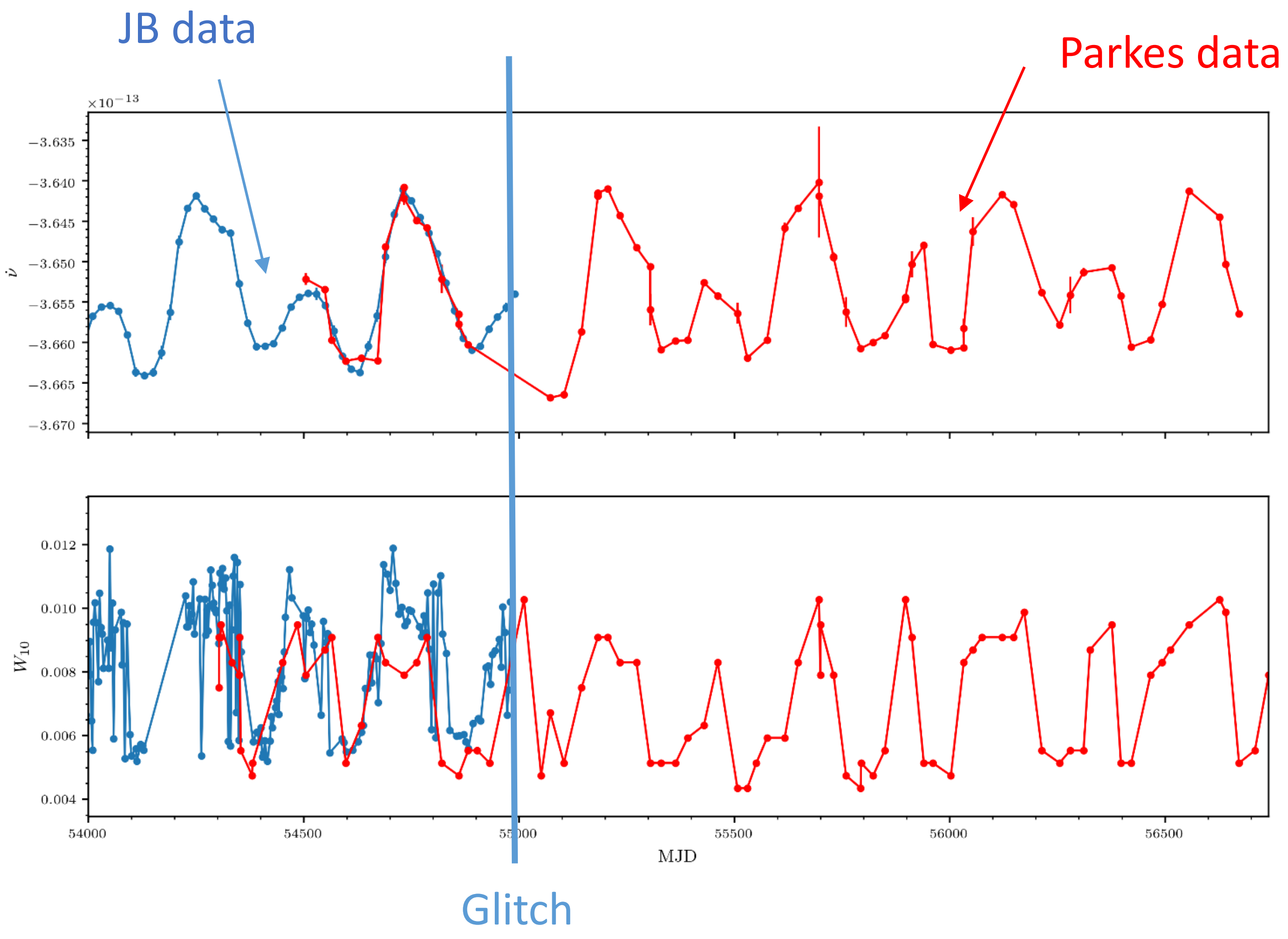
- Jones, Ashton, Prix (2017) "Implications of the Occurrence of Glitches in Pulsar Free Precession Candidates"

- Looked for consistency between precession and the glitch

- For example:
  - Precession is related to "strain" in the star
  - A glitch may relieve strain in the star => decrease in the period over the glitch
  - $P_{\mathrm{fp}} \sim 18\,\mathrm{yr}$ after the glitch

Post-glitch data

- Ashton, Jones, Prix in prep.
- Taking a set of data from the Parkes open data catalogue (https://data.csiro.au/dap/public/atnf/pulsarSearch.zul)
- No obvious change of the glitch, current work: testing for any subtle changes.
- This doesn't rule out precession, but constrains certain combinations of precession and glitches



Status of models

Precession

- Physical model naturally predicts modulations
- Patchy emission beam required to explain short-term variations
- Difficult to understand changing modulation period
- Difficulties reconciling this with the glitch

Switching

- Fits the picture of other nulling/mode-switching behaviour
- What is the clock?
- Why is the clock stable on long-time scales, but varies on short-time scales?
- Why is the clock speeding up?

Question: is there any change in the modulation over the glitch?

Back to planets?

- A planetary hypothesis where the planet applies a torque
- Naturally explain the increasing modulation period: inspiral
- Test: any change in the modulation period over the glitch would rule this model out

Conclusions

- PSR B1828-11 displays several unique patterns
  - Correlated periodic modulations in the spindown and pulse shape
  - The modulation period is decreasing at a rate of 0.01 s/s
  - The pulsar glitches

- This pulsar may be "special"

- But, Hobbs et al. (2010) and Lyne et al (2010) suggests many pulsars undergo (quasi-)periodic behaviours on timescales of >yrs