The deepening mystery of the Vela radio-pulsar glitch

07/01/21: For the Department of Physics, Bar-Ilan University

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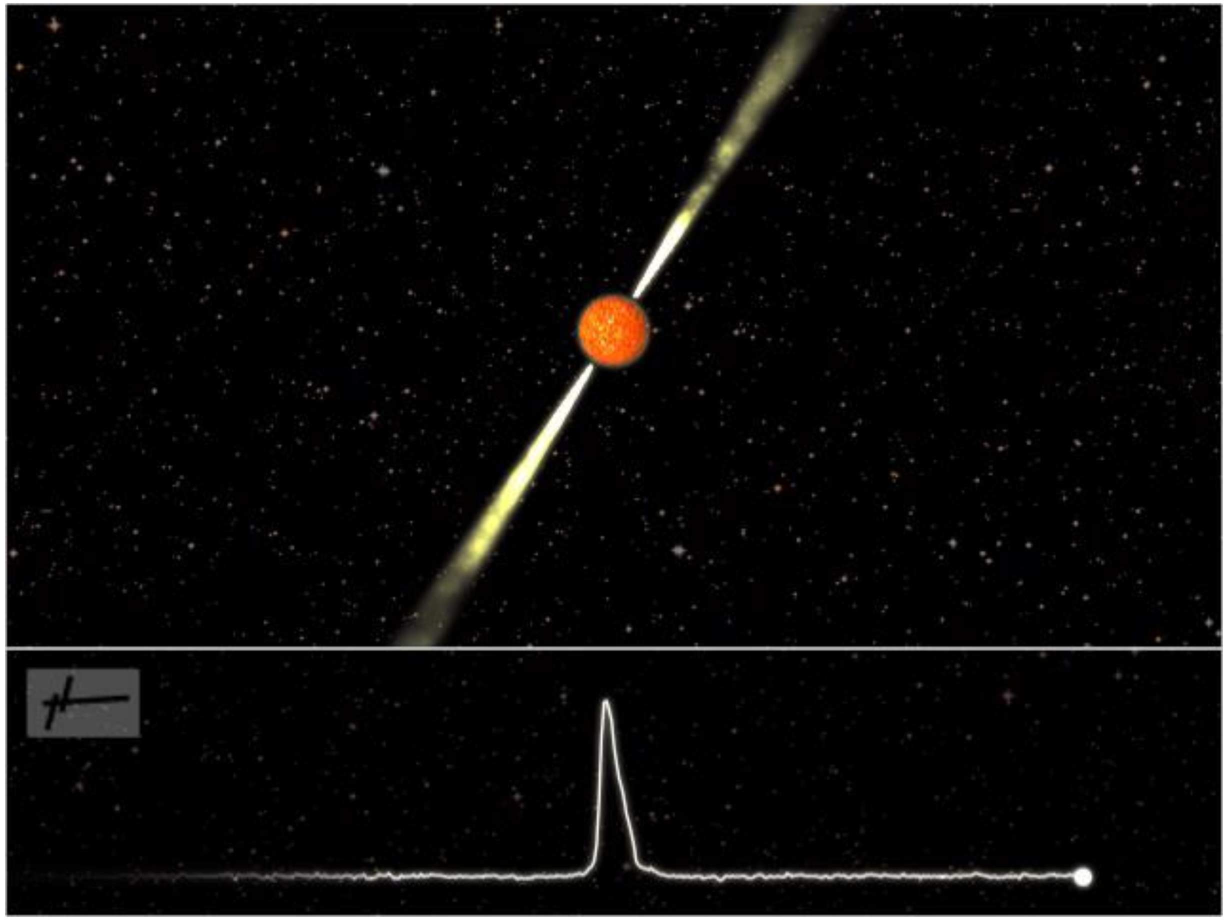
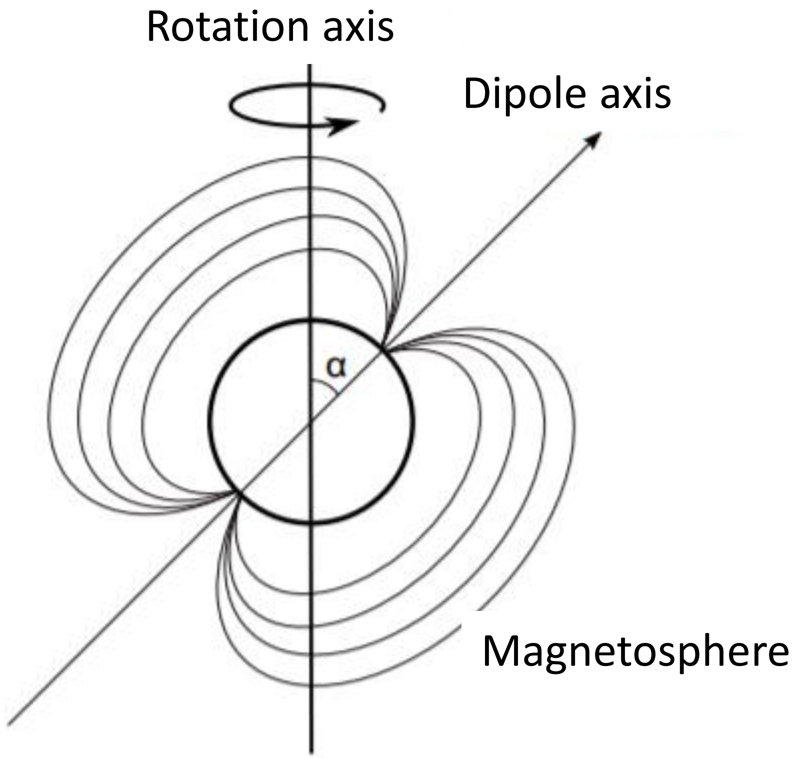
Radio pulsars: rotating neutron stars

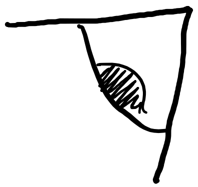


[Credit: Joeri van Leeuwen]

Isolated pulsars spin down

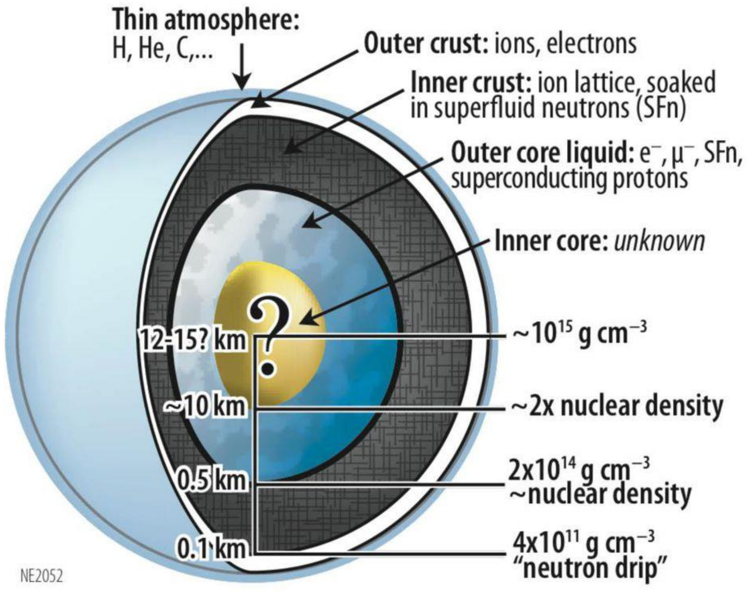
- Rotating dipole generates a torque,
- This gradually slows the pulsar



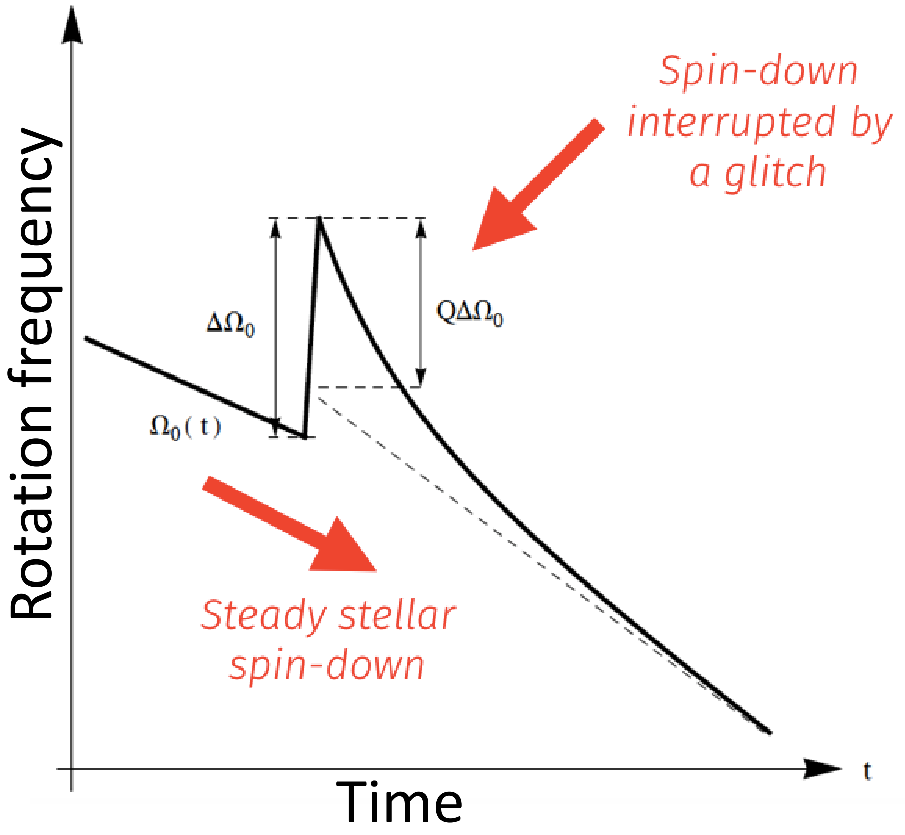


Radio pulsar glitches

- Sudden spin-up event
- Coupling of the inner and outer crust
- Provides insights into the interior



NASA / GSFC / NICER



Middleditch et al. (2018)

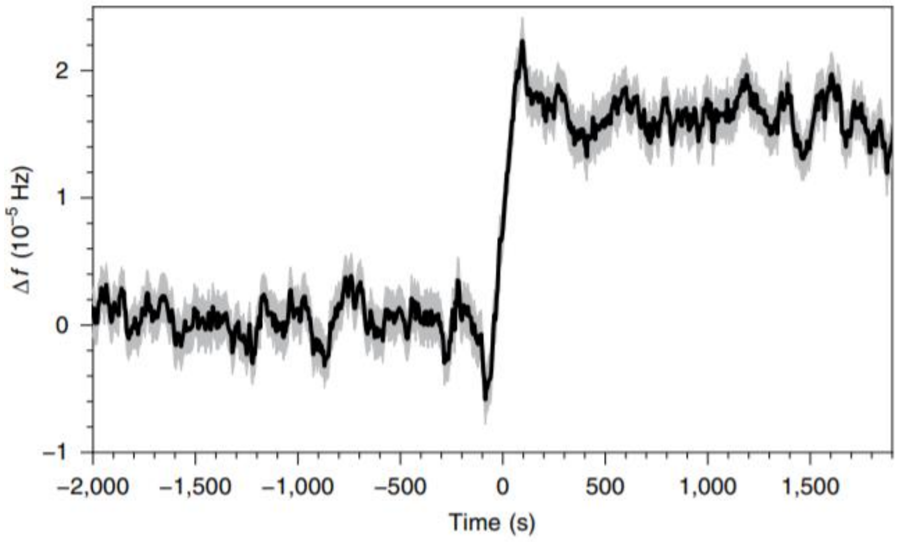
The 2016 Vela radio-pulsar glitch

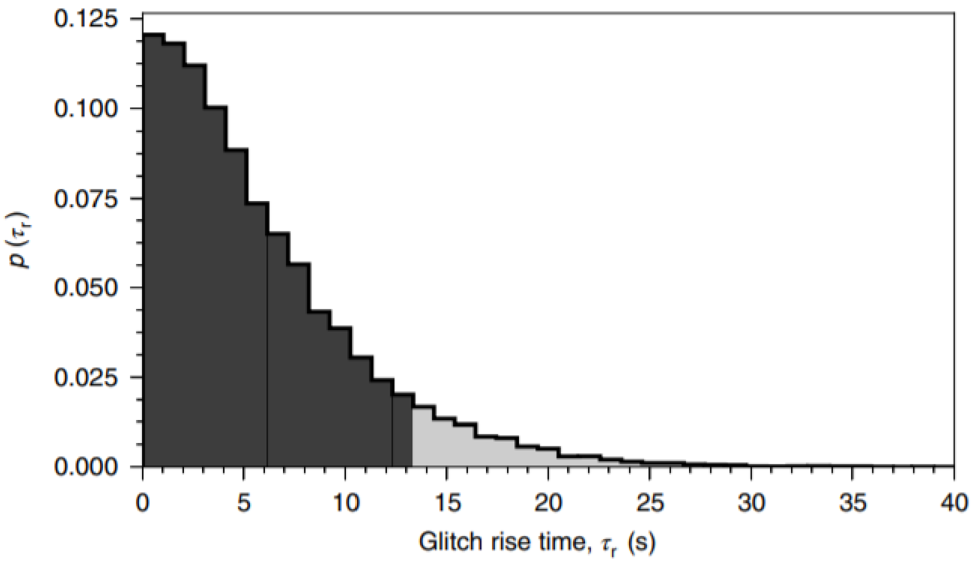
- Mt Pleasant Observatory Tasmania
- Constantly surveilling the Vela pulsar
- In 2016 it caught a glitch in real time:

  “Pulse-to-pulse observations”
- [Palfreyman et al. (2018)]

Seeing the spin-up

- The data allowed us to see the spin-up itself, for the first time:





Ashton et al. (2019)

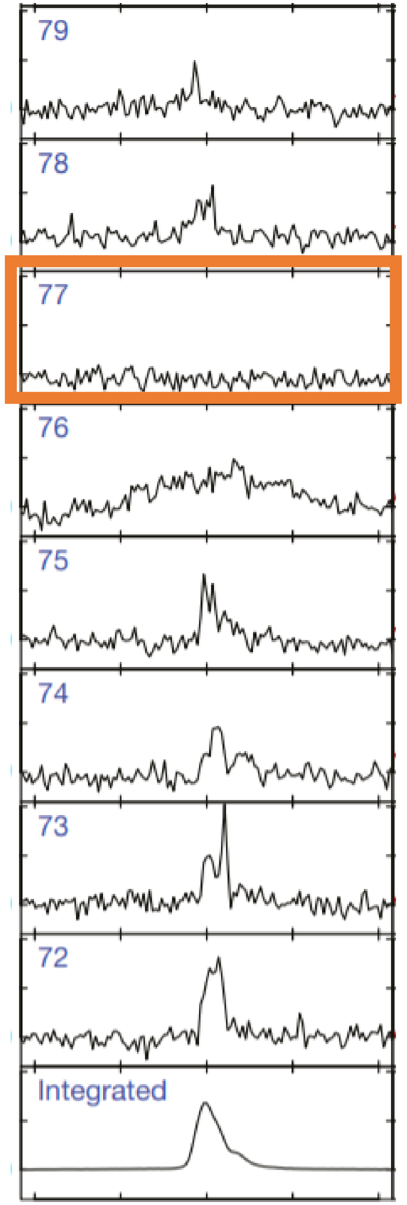
A null just prior to the glitch?

- This data allowed Palfreyman to analyze individual pulses during the glitch.

- While **integrated pulses are stable**: pulsars are known to exhibit significant **jitter**.

- A null, pulse 77, occurred just before the glitch.

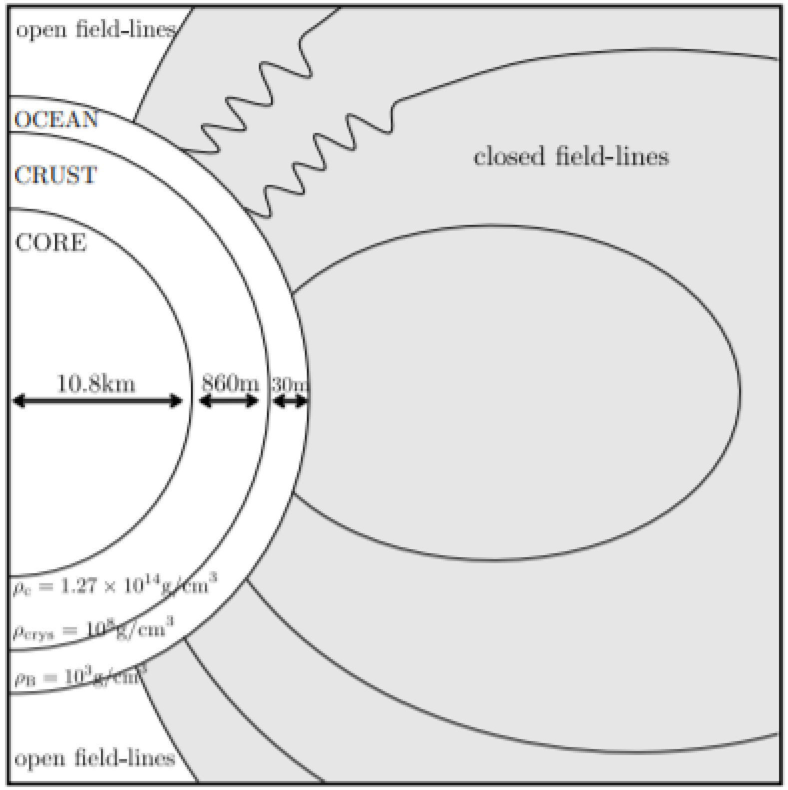
- This was the first ever null seen in the Vela pulsar



Palfreyman et al (2018)

Implications of the null

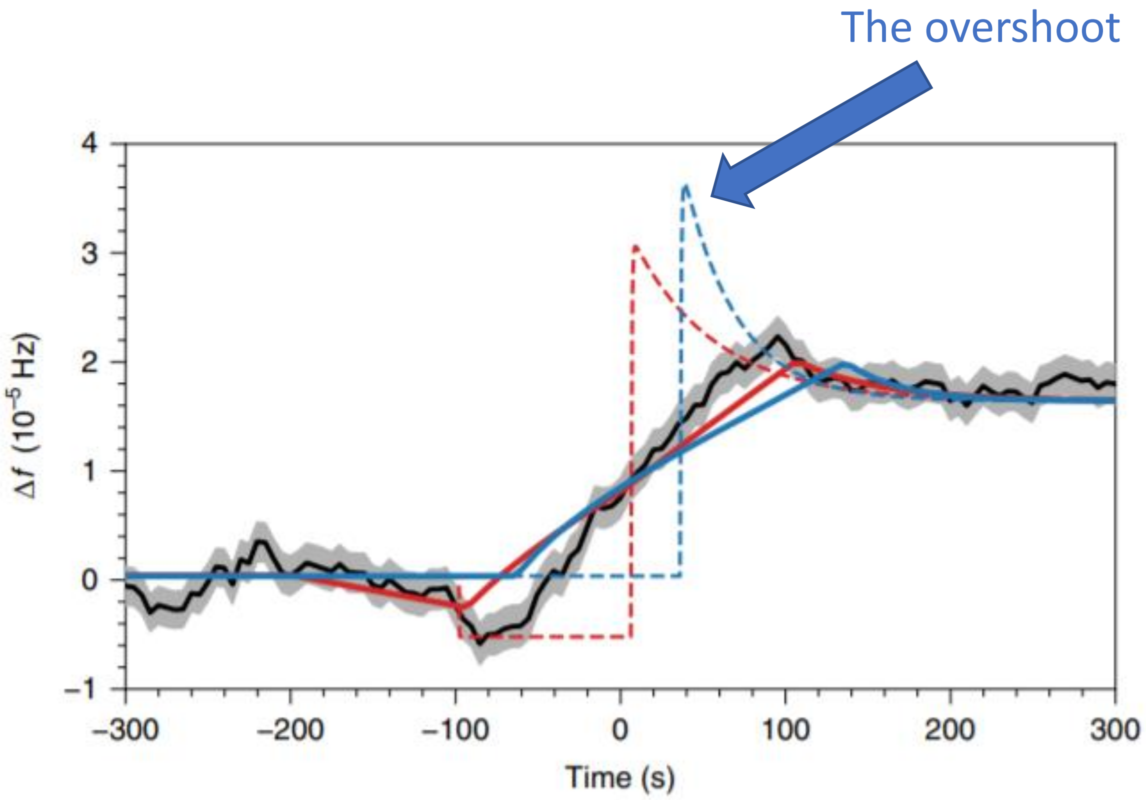
- Bransgrove et al. argue the null is caused by a **quake** deep in the crust of the star
- The **crust-quake:**
    - Quenches the magnetosphere
    - And triggers the glitch
- Based on the $\sim$0.2 delay, they infer that the quake happens deep in the crust
- The glitch itself is a superfluid unpinning



[Bransgrove et al. (2020)](#)

Using the dynamics to probe the physics

- We fit phenological models to infer the glitch properties
- We find overwhelming evidence for an “overshoot”

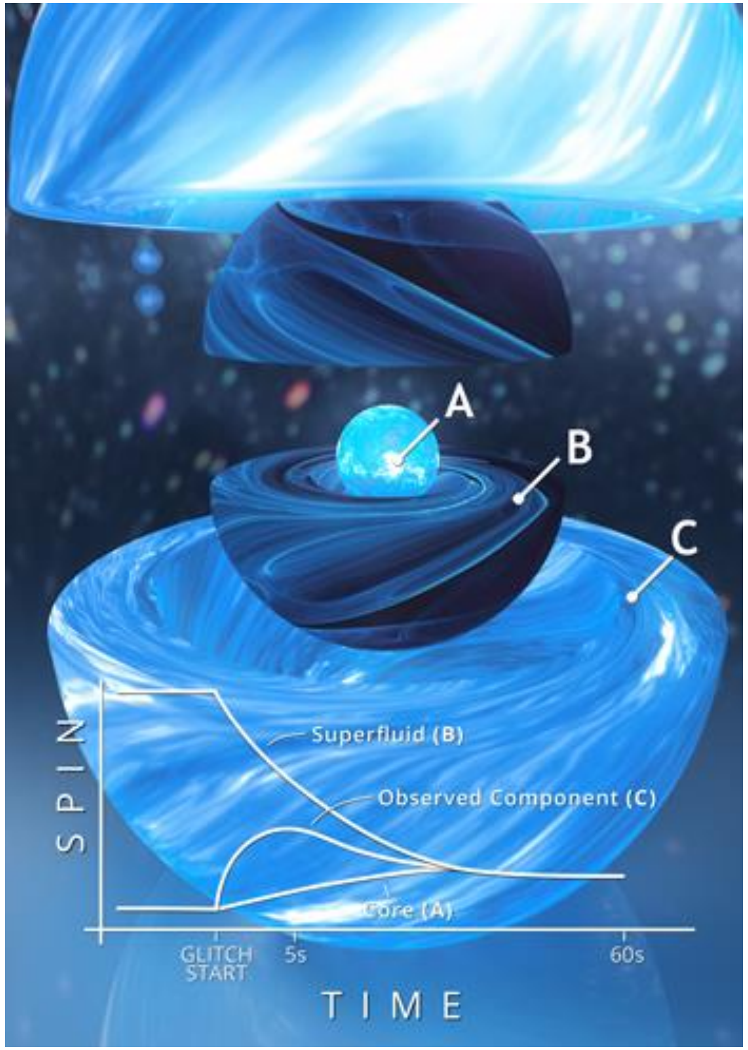


Evidence for three-components

- The overshoot provides the first evidence for the existence of three separate components

- This allows measurements of:
  - the moment of inertia of and
  - coupling of the components:

- See:
  - [Gügercinoğlu et al. (2020)]
  - [Montoli et al (2020)]

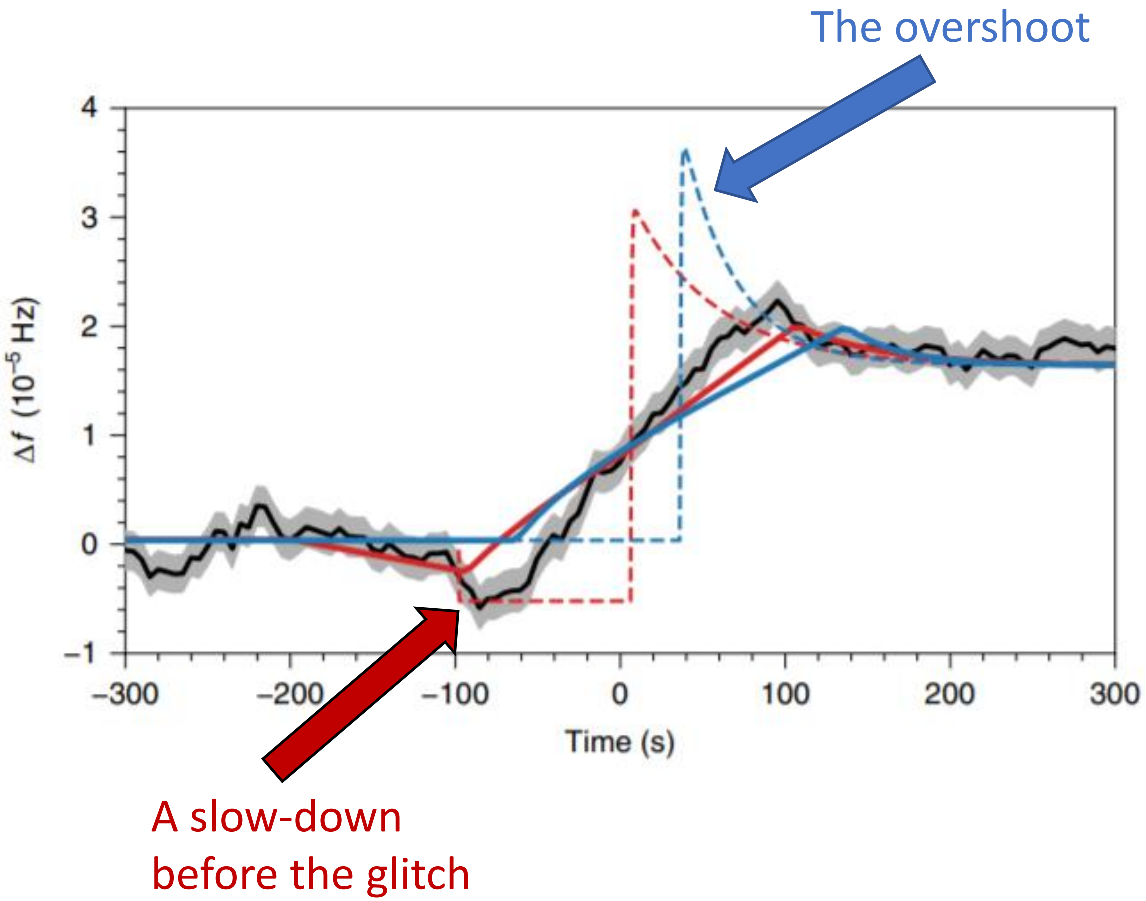


Using the dynamic to probe the physics

- We fit phenological models to infer the glitch properties

- We find overwhelming evidence for an “overshoot”

- We also find evidence for a slow-down prior to the glitch
  - A glitch pre-cursor anti-glitch?



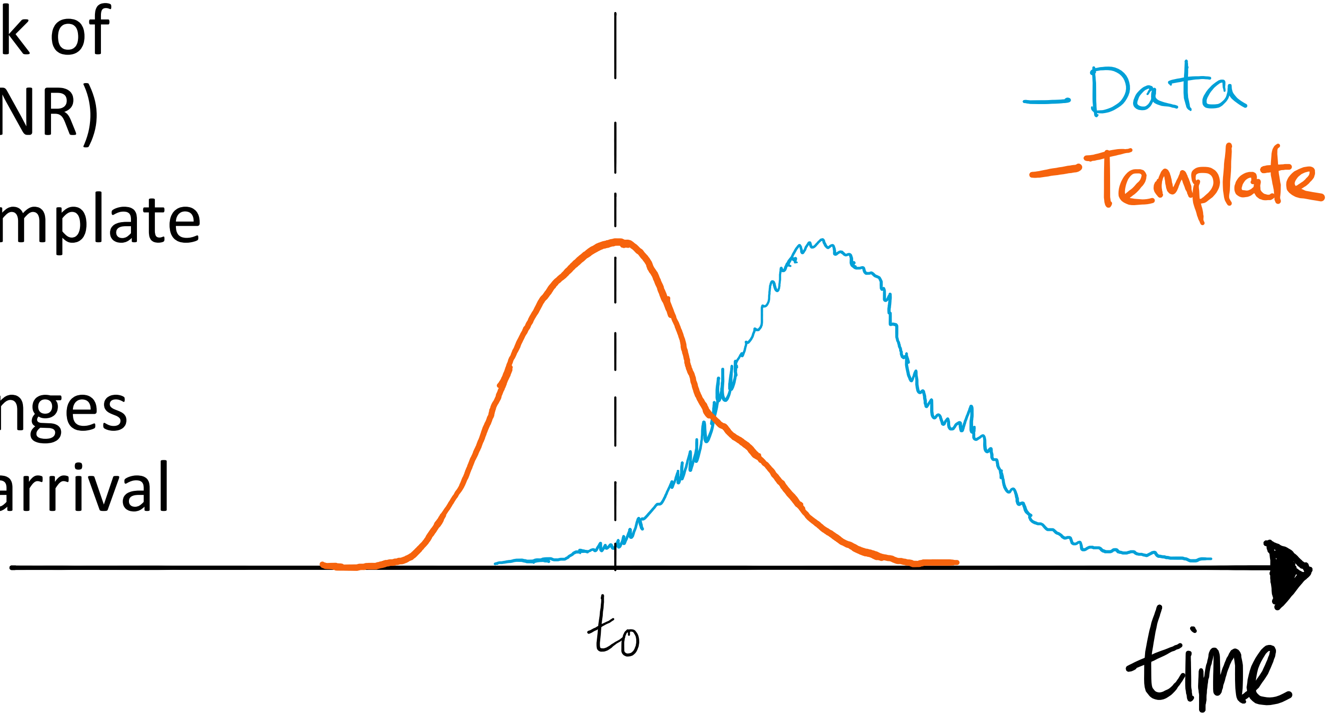
A pre-cursor glitch anti-glitch?

- It is difficult to develop a model for the pre-cursor slow-down
  - Gügercinoğlu et al. (2020) suggest it is consistent with the formation of a new superfluid vortex trap
  - But it needs a significant portion of the MoI involved to make it work
  - Does the slow-down trigger the glitch?
  - What triggers the slow down?
  - Is the slow-down related to the Bransgrove crustquake?

- Instead, it could be that what we observe as a slow-down is an artefact of the data analysis

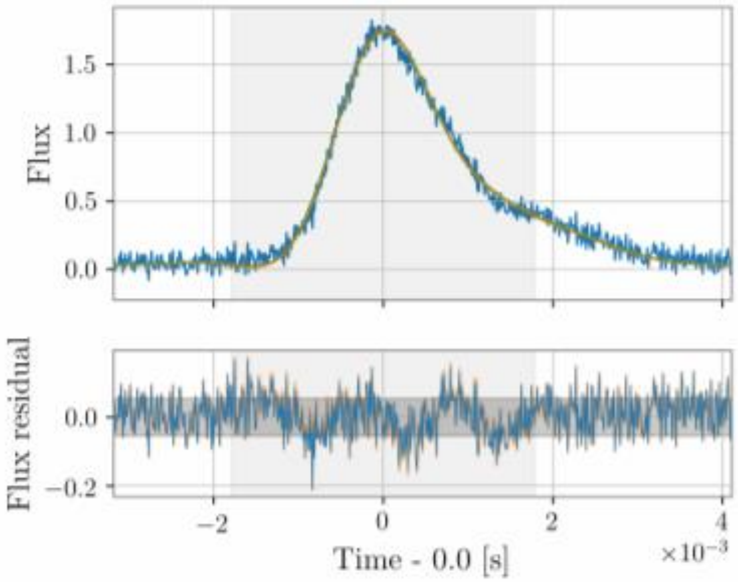
Aside on traditional pulsar timing

- Matched-filter a **fixed template** against the data
- Pulse arrival time is the Peak of the Signal-to-Noise Ratio (SNR)
- Subject to bias when the template is not a good fit to the data
- Systematic pulse shape changes manifest as changes in the arrival time



Profile-domain timing

- Fit a parameterized model
- We use a shapelet-based model (sum of Hermite polynomials + Gaussians)
- Code available: github.com/GregoryAshton/kookaburra

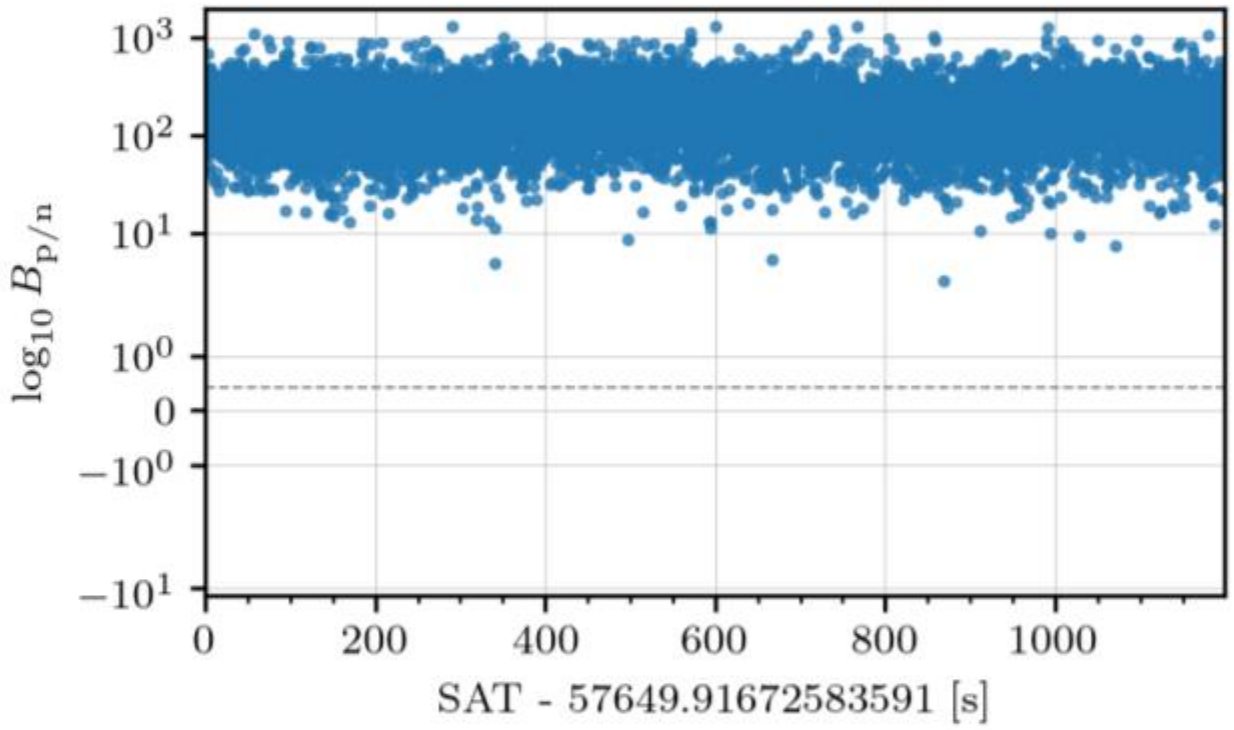


Profile-domain timing and the Vela glitch

- Analyzing 30,000 pulses surrounding the glitch, we found know evidence for systematic pulse-shape changes.
- Implies the anti-glitch can’t readily be explained by pulse-shape changes

Identifying nulls

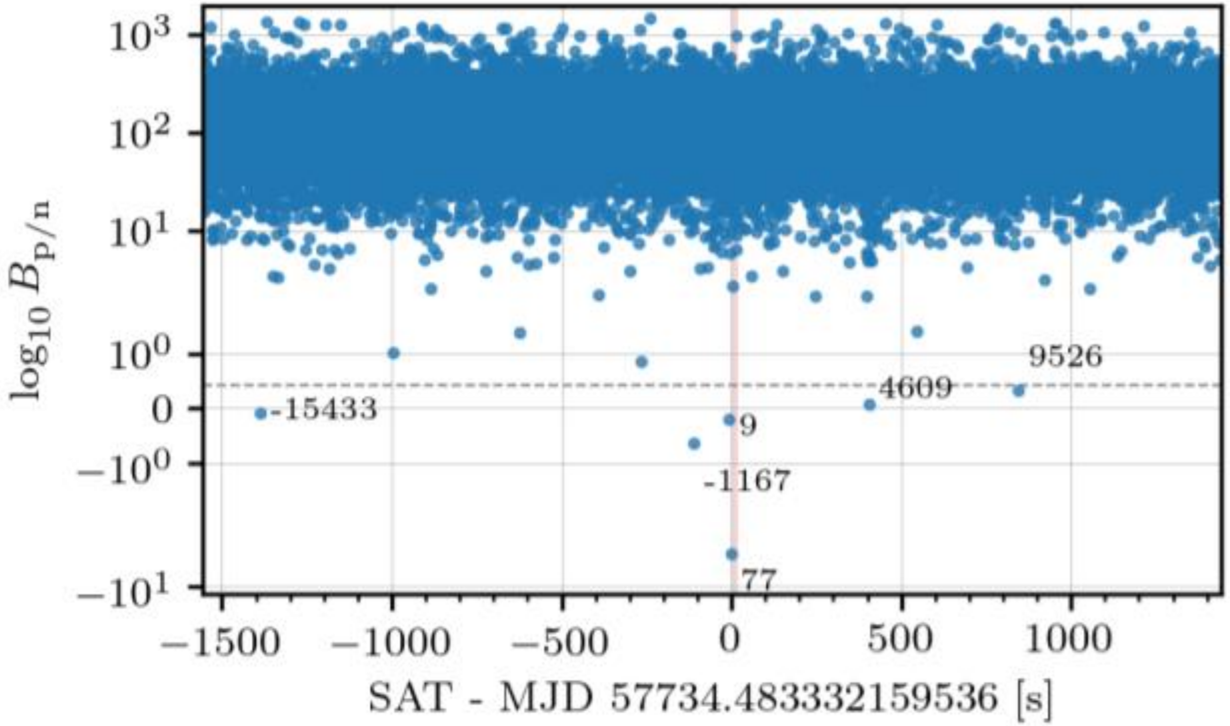
- We can use profile-domain timing to identify nulls
- Calculate a “Bayes factor” for pulse vs. null
- In data away from the glitch we do not see nulls



(b) Data from MJD 57649, 85 days before the glitch.

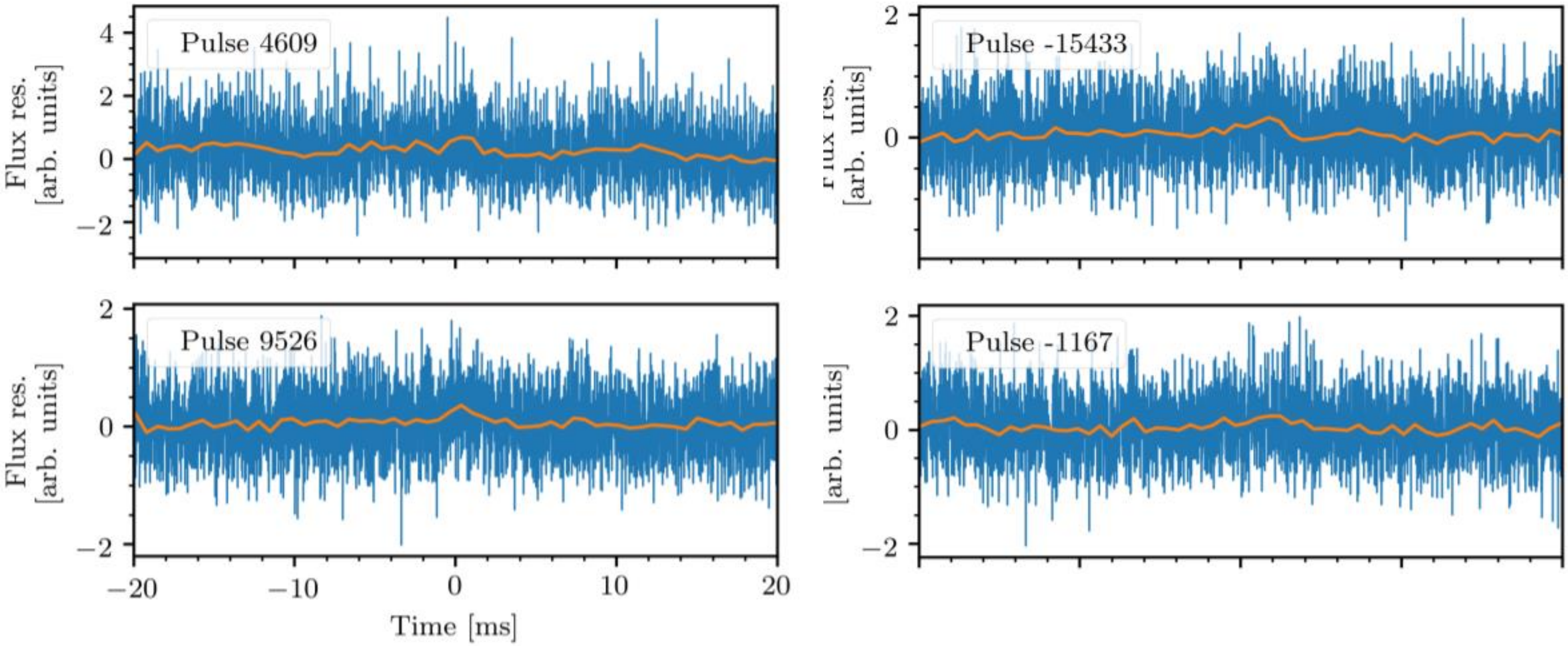
Flickering

- In data surrounding the glitch we see **the null**, pulse 77.
- We also see several other outliers that we term **quasi-nulls**.



[Ashton et al. (2020)](#)

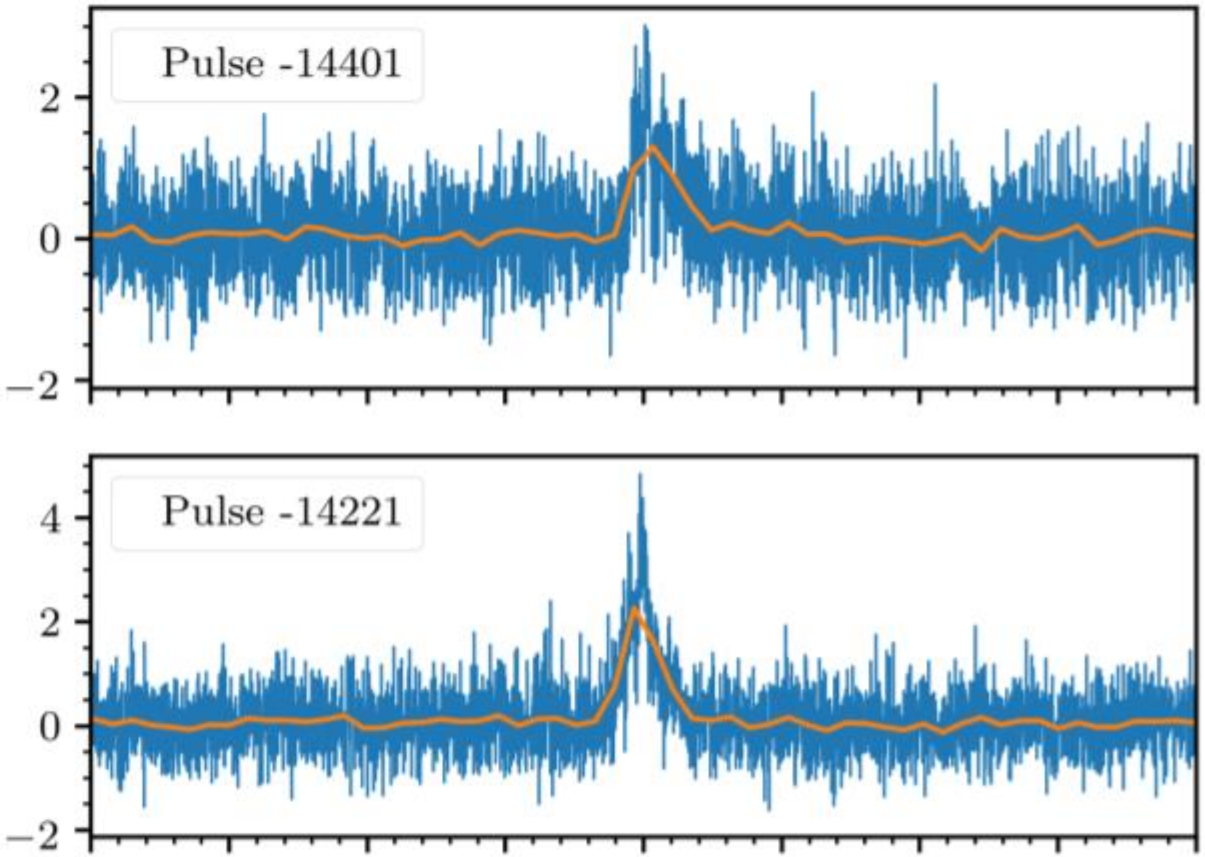
Looking at the data around quasi-nulls



Comparing to regular pulses

- Comparing quasi-nulls to regular pulses (right)

- Clearly quasi-nulls are different



What do quasi-nulls tell us?

- The crust-quake picture of Bransgrove et al. needs rethinking!
- Either there are a series of crust-quakes near to the glitch, but only one triggers the glitch
- Or the quasi-nulls are not sourced by crust-quakes

The story so far

- The Vela glitch gives us an unprecedented opportunity to study the interior of neutron stars
- We have the first evidence for three distinct components in the neutron star
- We have two mysteries:
  - Is the pre-cursor slow down physical and what causes it?
  - What do the quasi-nulls tell us about the interaction between the magnetosphere and the star itself?

Future opportunities

- The Vela pulsar will glitch again!
- Better future observations will give a clearer view of the phenomena we have already seen.
- It glitched in 2019 (Atel #12466), but Mt Pleasant wasn't ready.
- If quasi-nulls occur minutes before glitches, we can use them to construct an early warning system.
- Tentative searches for transient-continuous gravitational wave emission should also be performed (Yim et al. (2020))