Rotational glitches

Two different mechanisms?

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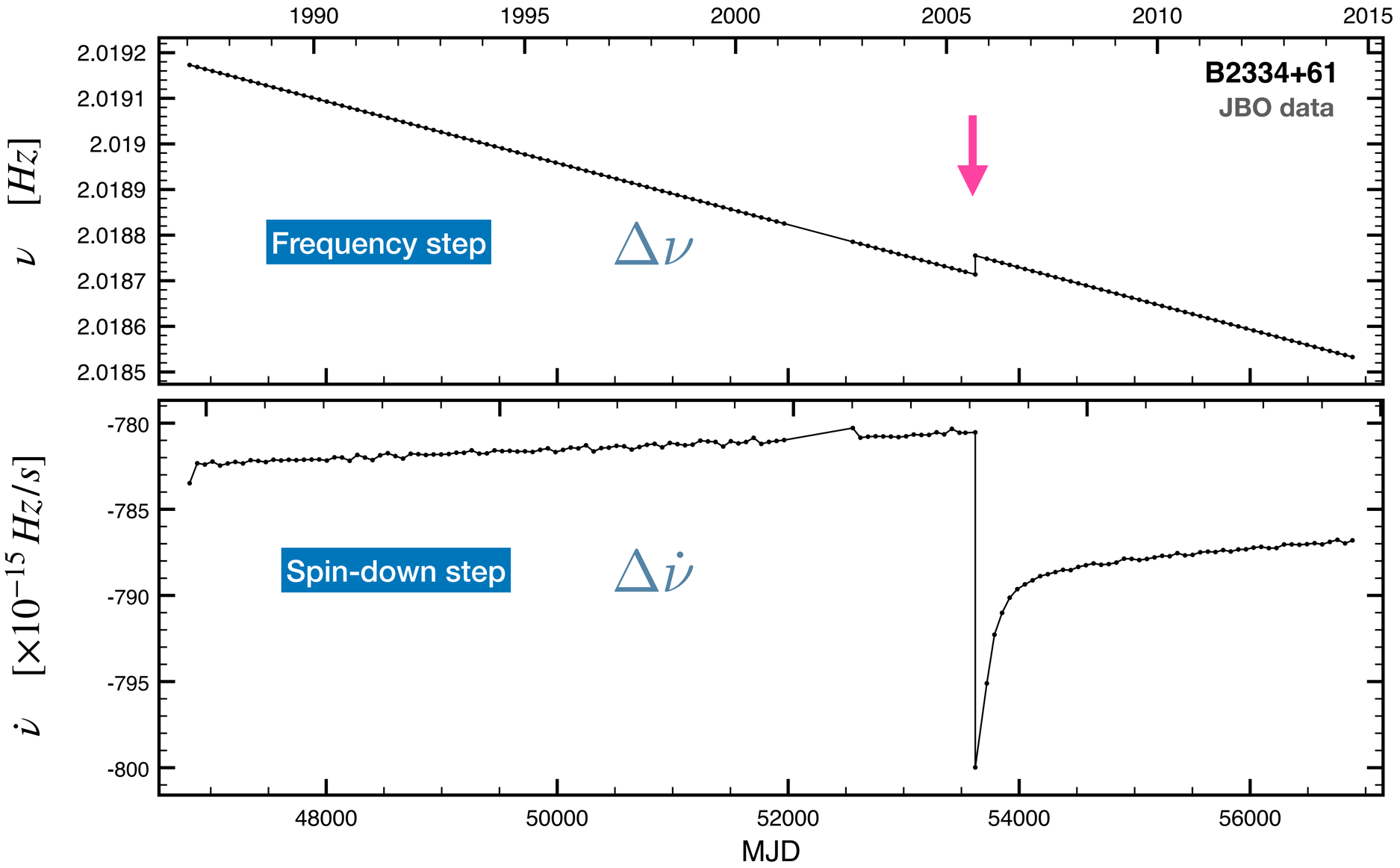
RESEARCH IN ASTROPHYSICS
AND SPACE SCIENCES

Glitches

- Occasional spin-up events (1 every 50 yr *in average*).



What can produce a glitch?

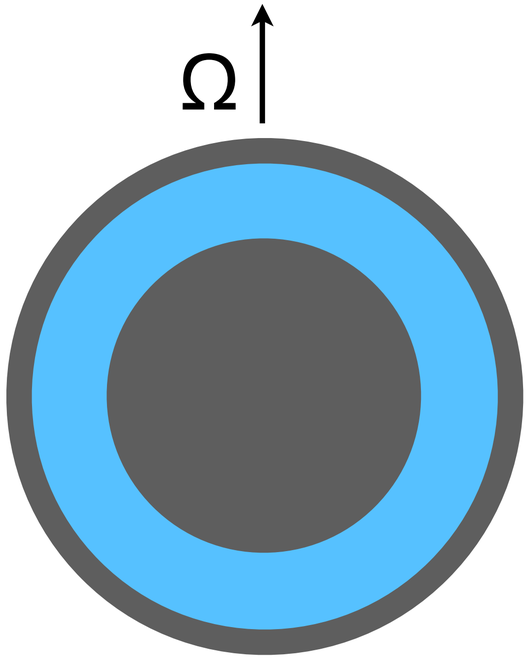
✦ Star-quakes: spin-down driven or magnetic.

e.g.: Rencoret+2021

✦ Superfluid - crust interaction:

- Superfluid neutrons can be weakly coupled to the rest of the star.

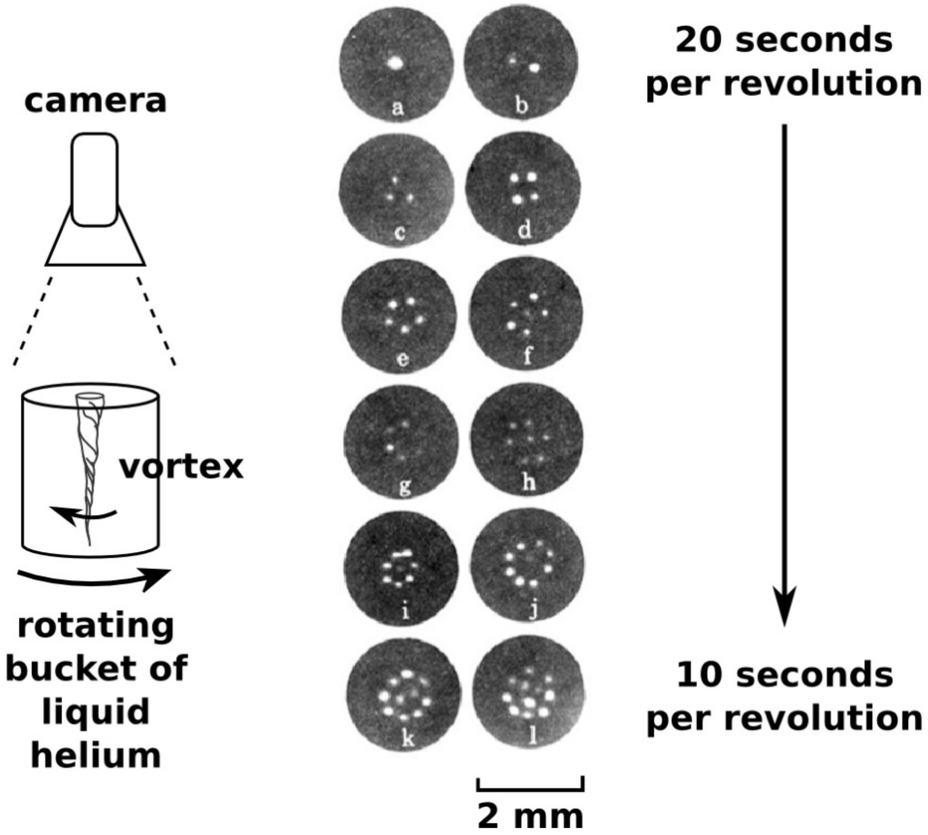
- They can store angular momentum.



Anderson & Itoh (1975)

Rotating superfluids

- Angular momentum is carried by vortex lines of quantised circulation
- Vortex number density defines rotation rate



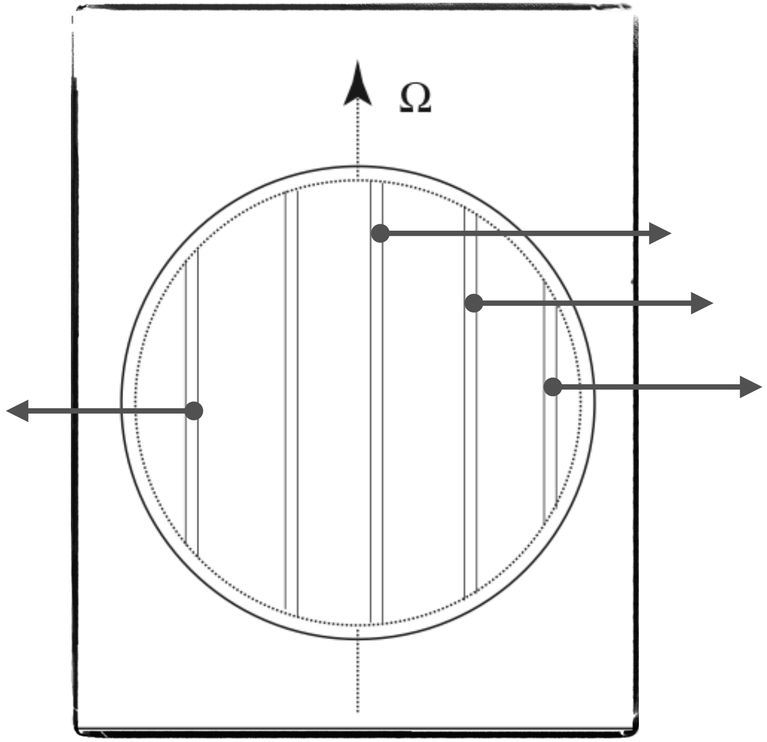


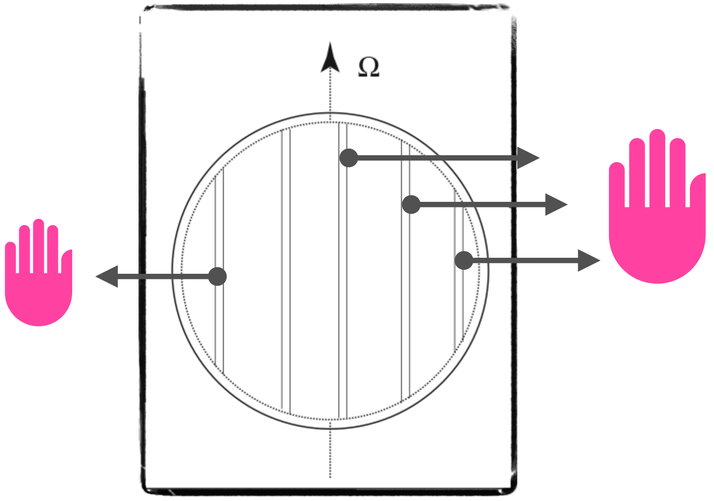
figure by Yarmchuk, Gordon, and Packard,1979

A two-fluid model for glitches

- Vortex pinning:

  If vortices are stopped in their migration, differential rotation builds.

Anderson & Itoh (1975)



Glitch happens when billions of vortices unpin

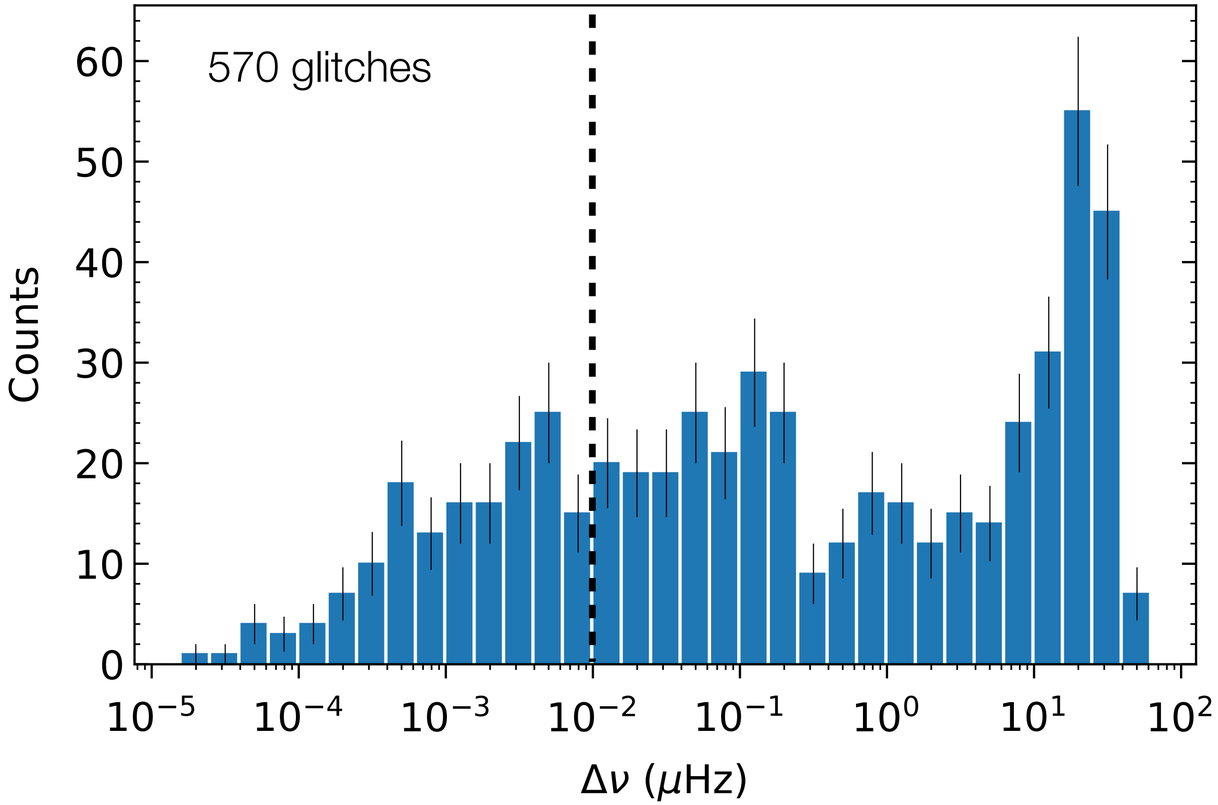
Possible triggers:

- Critical lag: $F_{\text{Magnus}} > F_{\text{pinning}}$ > Alpar et al. (1984); etc.
- Instabilities > Glampedakis & Andersson (2009)
- Avalanches > Melatos et al. (2008, 2009)
- Thermal unpinning by heating event. > Link & Epstein (1996)

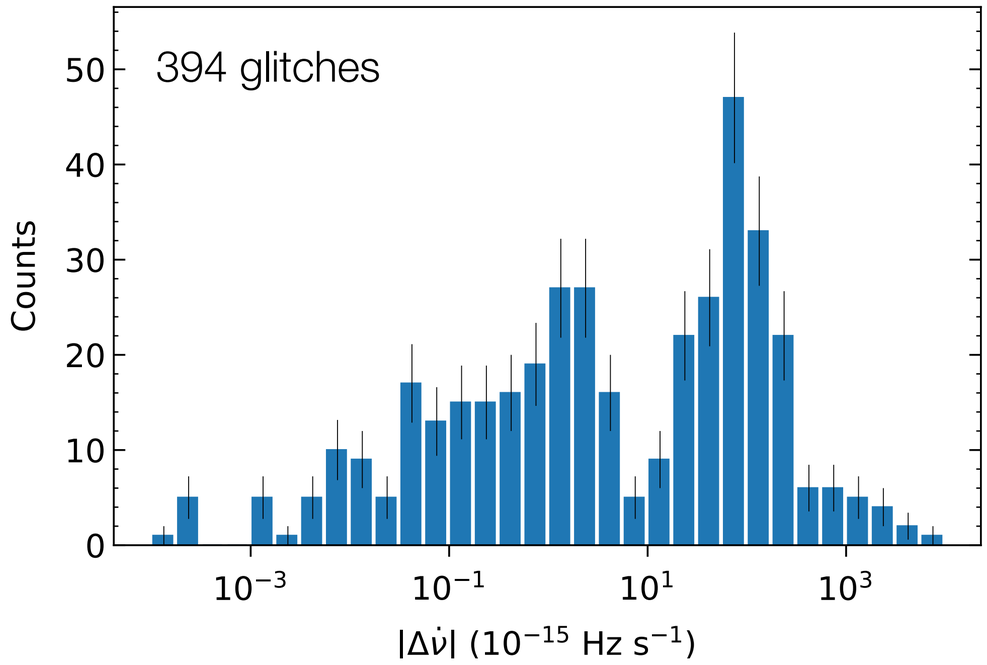
Model reviews:

- Haskell & Melatos 2015
- Antonopoulou, Haskell & Espinoza (2022, under review)

Frequency steps (log scale)



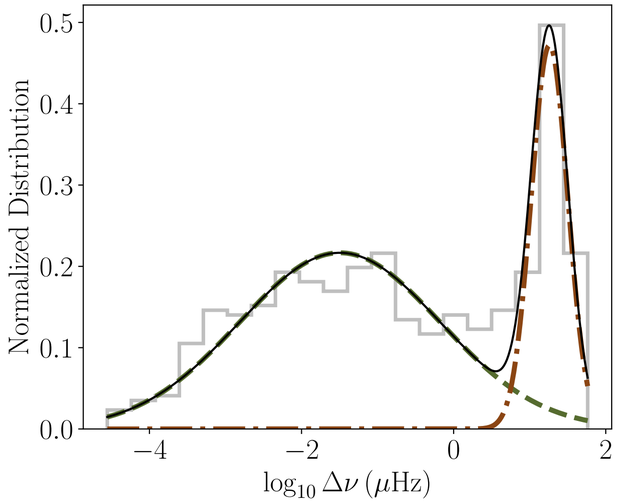
Spin-down rate steps



Antonopoulou et al. (2022, submitted)

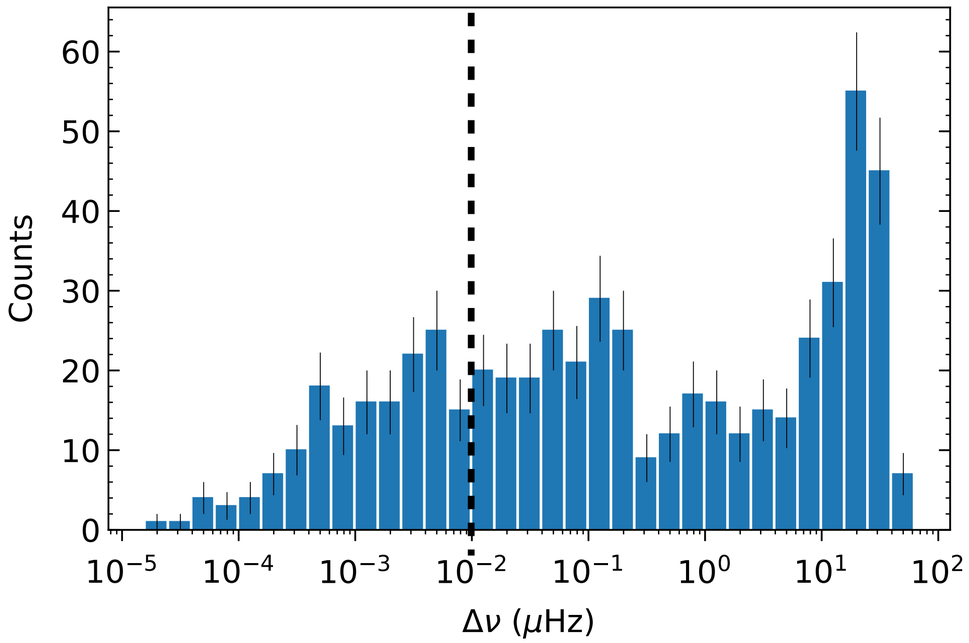
The distribution of all known glitch sizes is at least bimodal

Ashton+2017
Fuentes+2017
others.



Basu et al. (2022)

Frequency steps



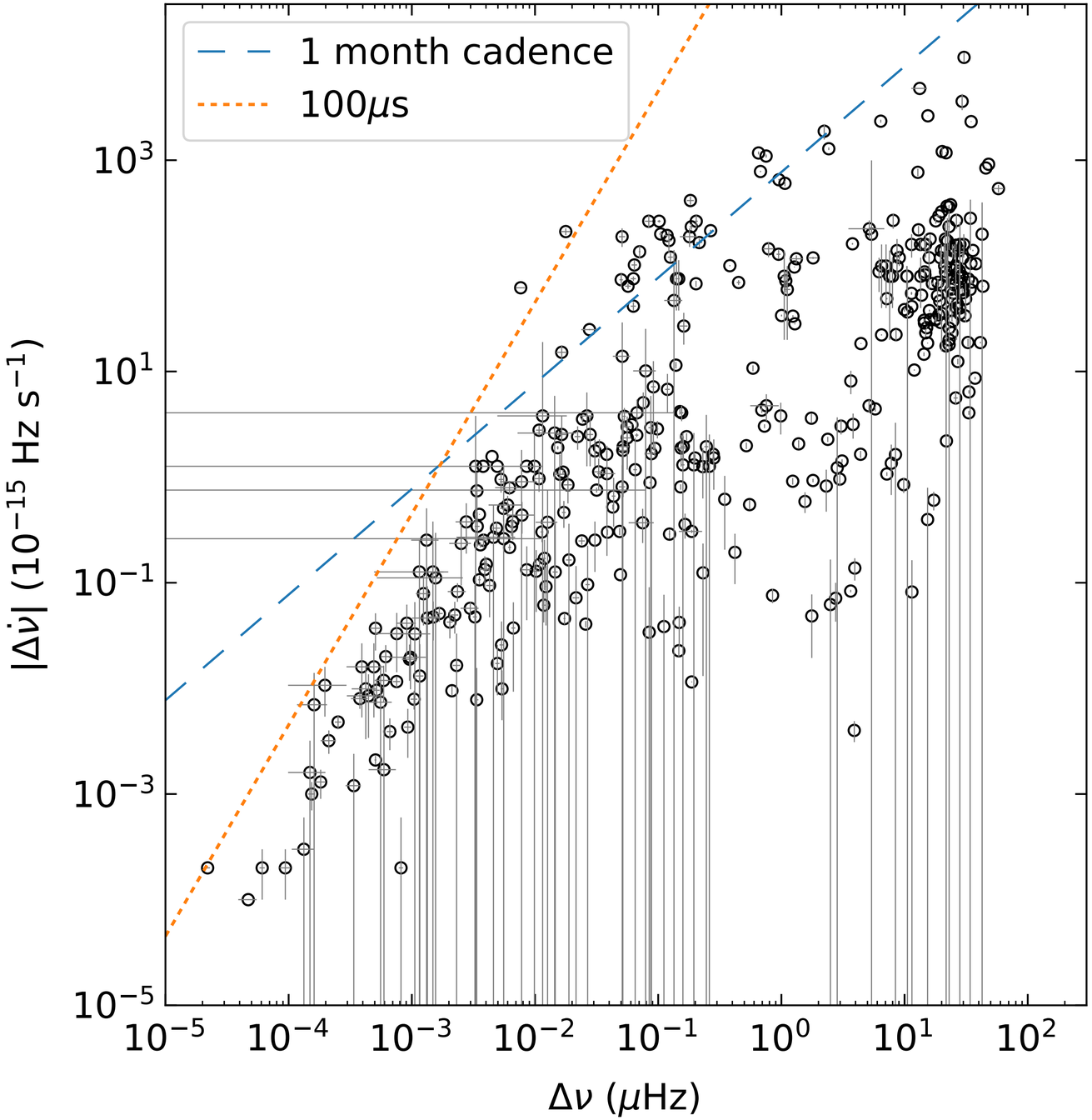
$$\Delta\nu_{\rm lim} = \max \begin{cases} \Delta T |\Delta\dot{\nu}|/2 \\ \sqrt{2\,\sigma_\phi |\Delta\dot{\nu}|} \end{cases}$$

The size of the smallest detectable glitch depends on:

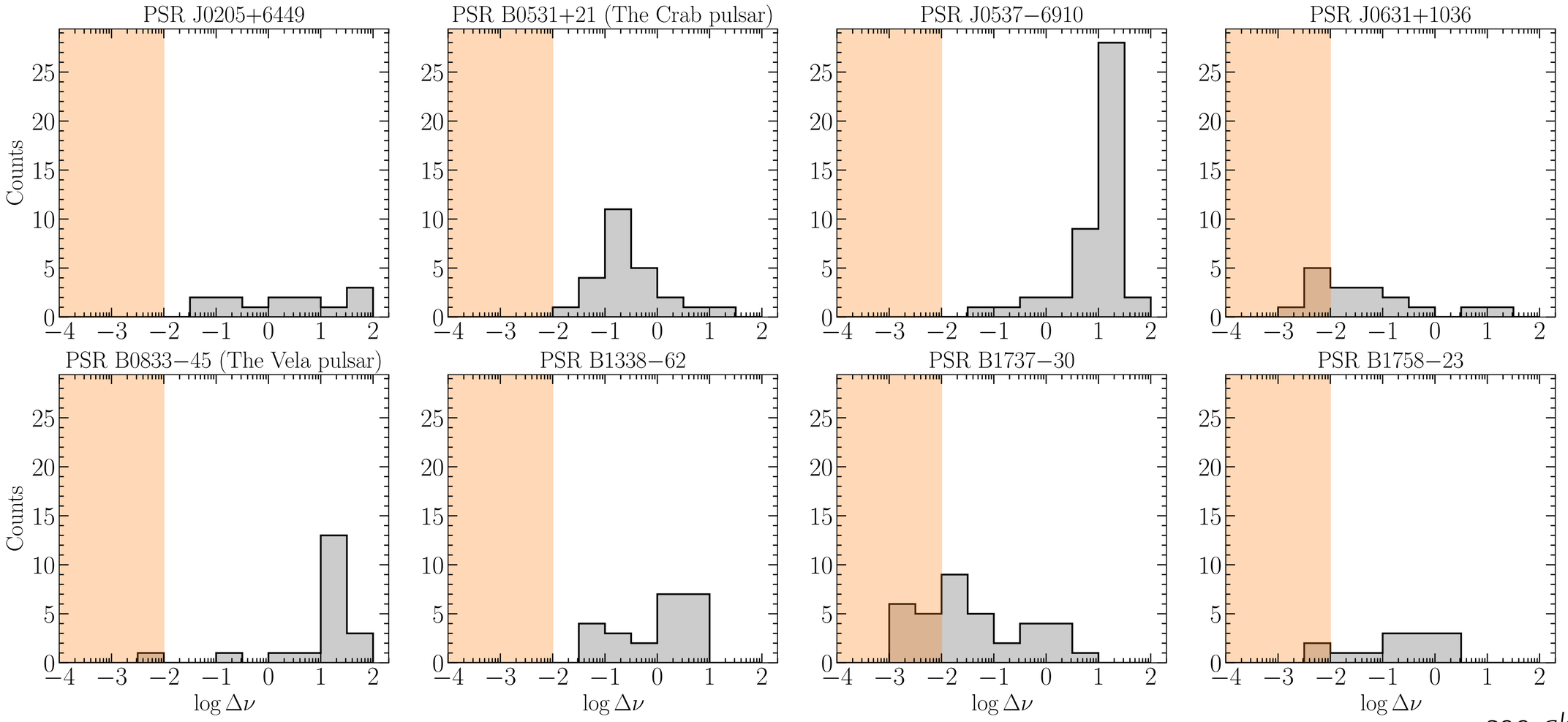
- **Cadence (ΔT)**
- **Sensitivity / noise (σ_ϕ)**
- **Size of spin-down step**

Espinoza+2014

Antonopoulou et al. (2022, submitted)



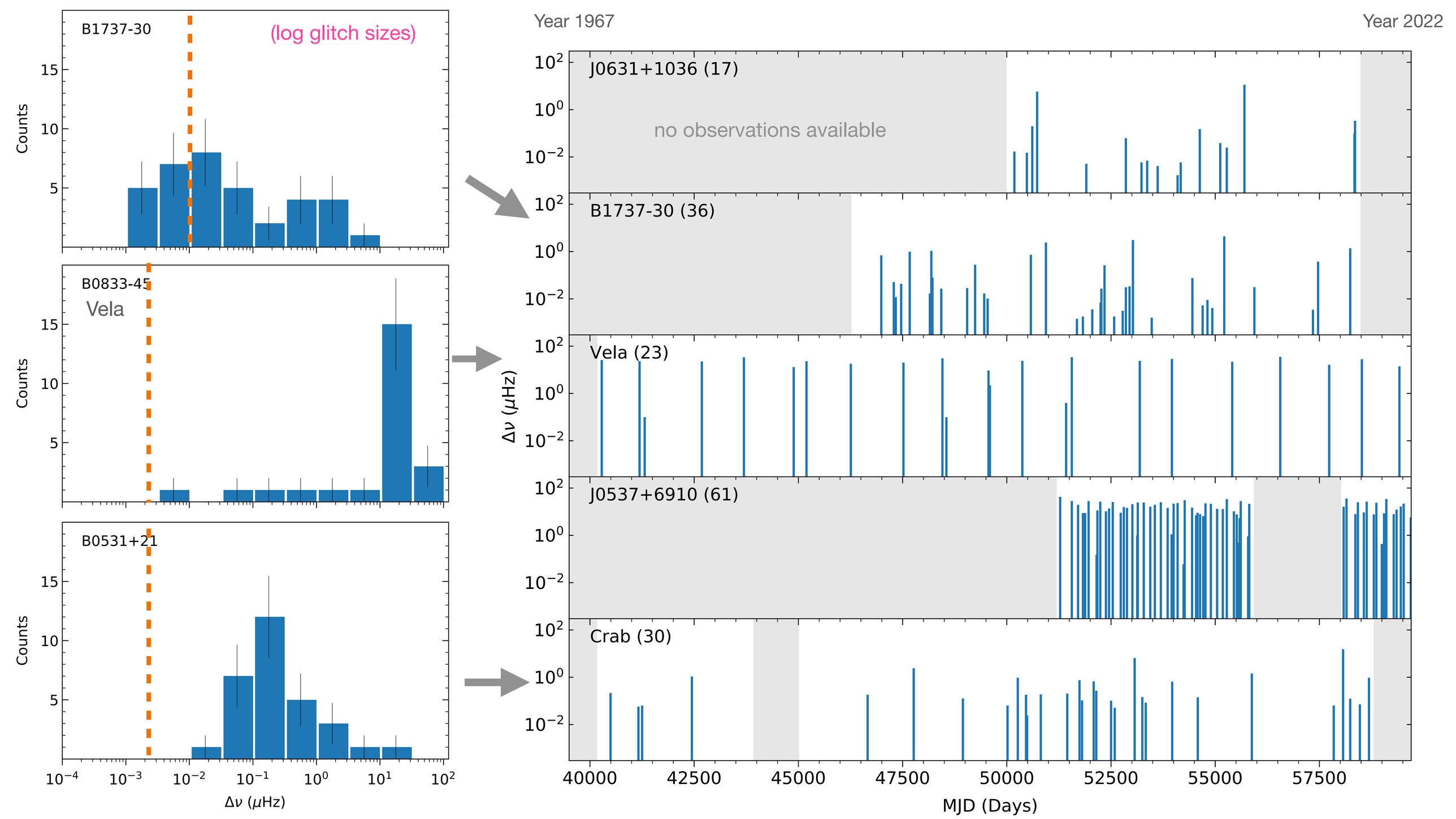
The size distributions of individual pulsars are not bimodal.



Fuentes+2019

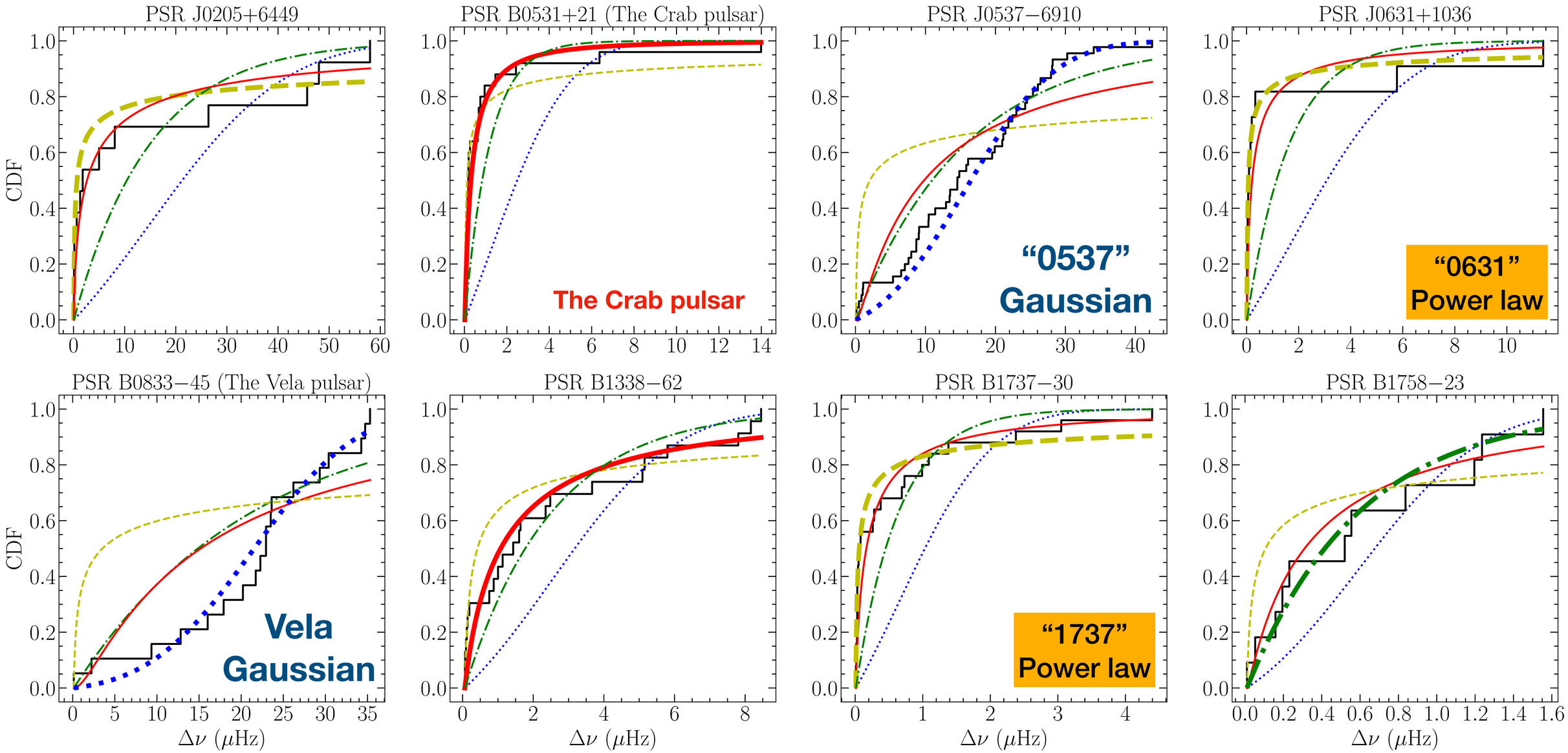
see also: Howitt+2018
Wang+2012
Melatos+2008

The 8 pulsars with 10+ detected glitches:


B1737-30
(log glitch sizes)
B0833-45
Vela
B0531+21
Counts
Δν (μHz)
Year 1967
Year 2022
J0631+1036 (17)
no observations available
B1737-30 (36)
Vela (23)
J0537+6910 (61)
Crab (30)
Δν (μHz)
MJD (Days)

Cumulative distributions of glitch sizes

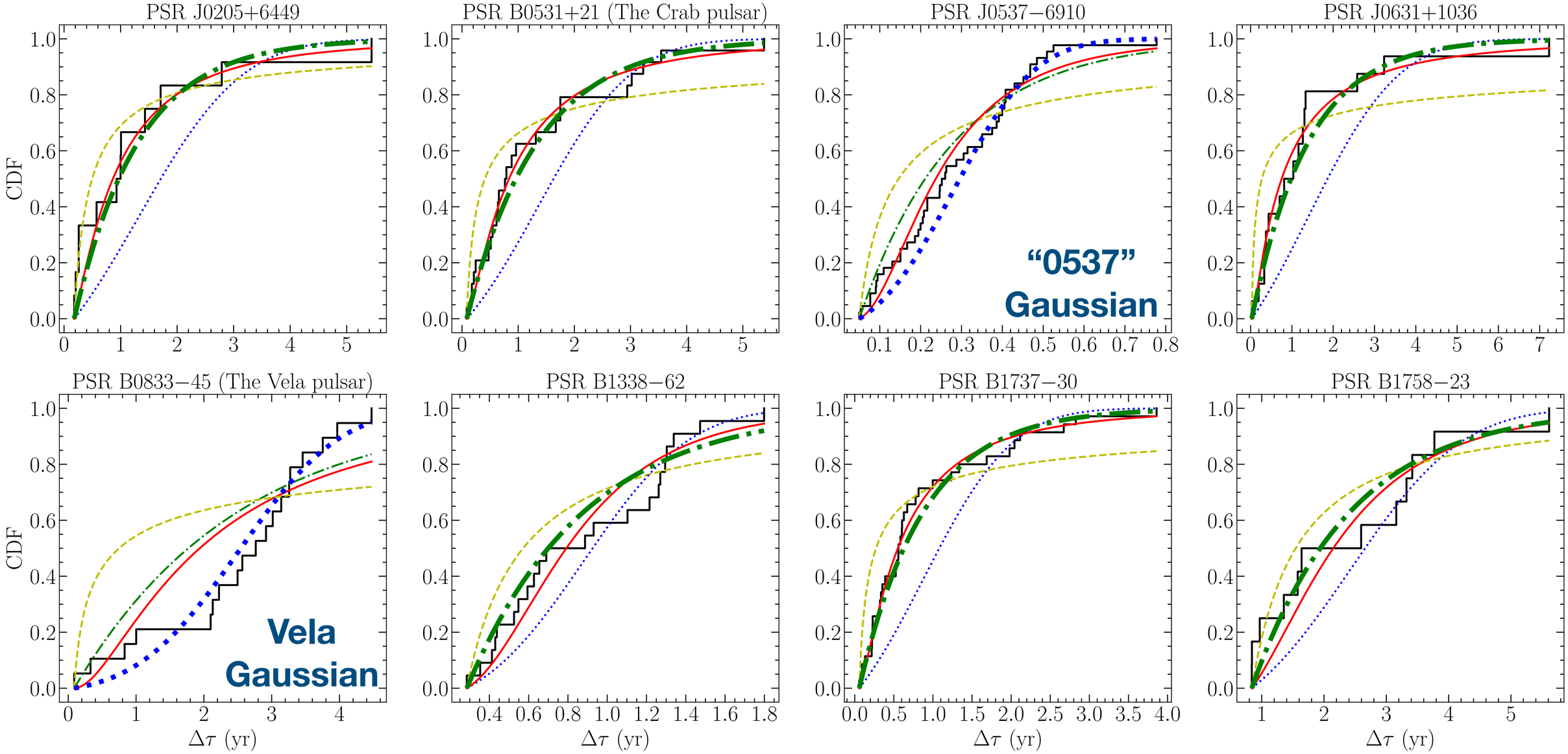
Fuentes et al. (2019)



See also: Melatos+2008; Fulgenzi+2017; Howit+2018; Liu+2018

Cumulative distributions of times between glitches

Fuentes et al. (2019)

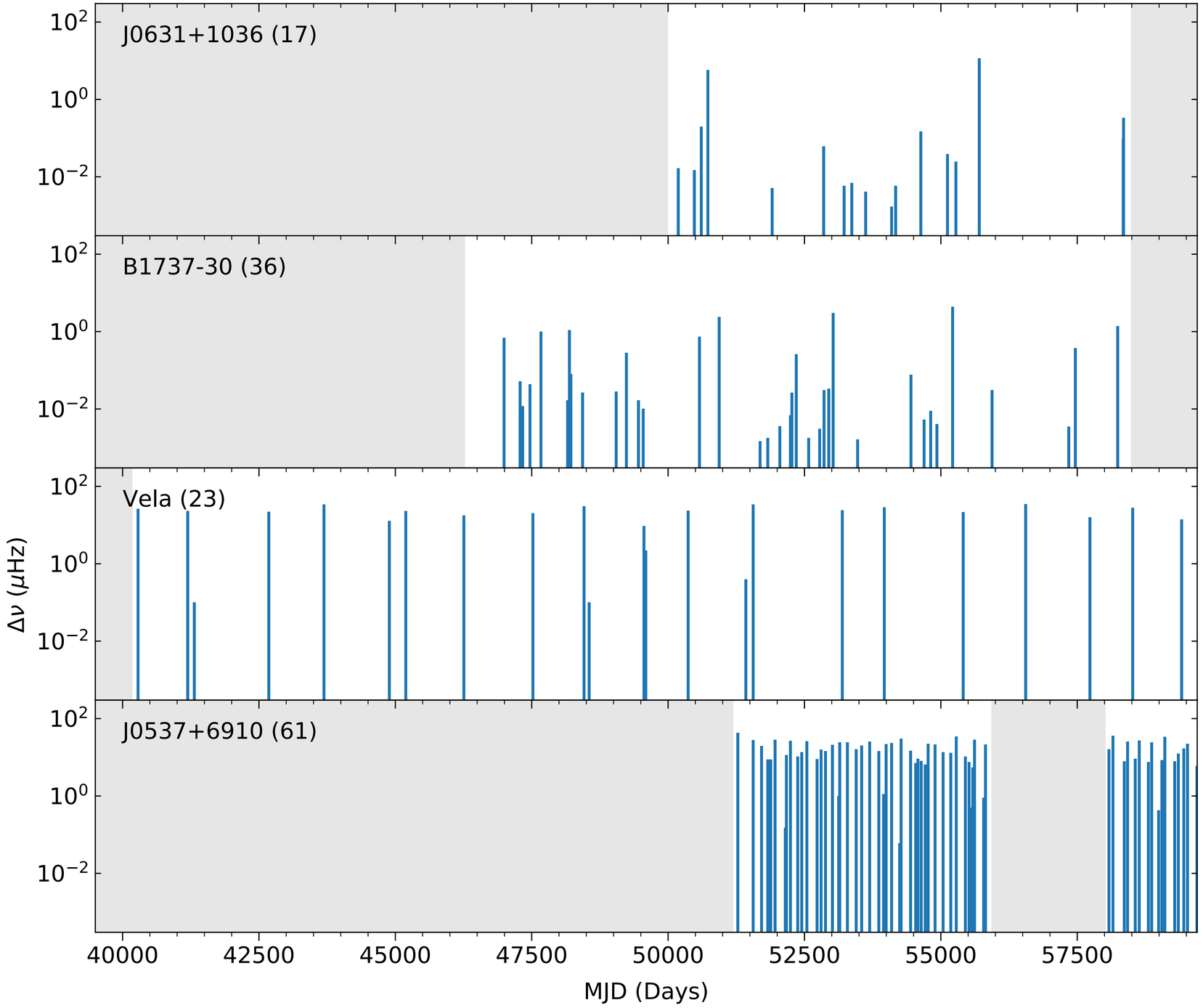


See also: Melatos+2008; Fulgenzi+2017; Howit+2018; Liu+2018; Millhouse+2022

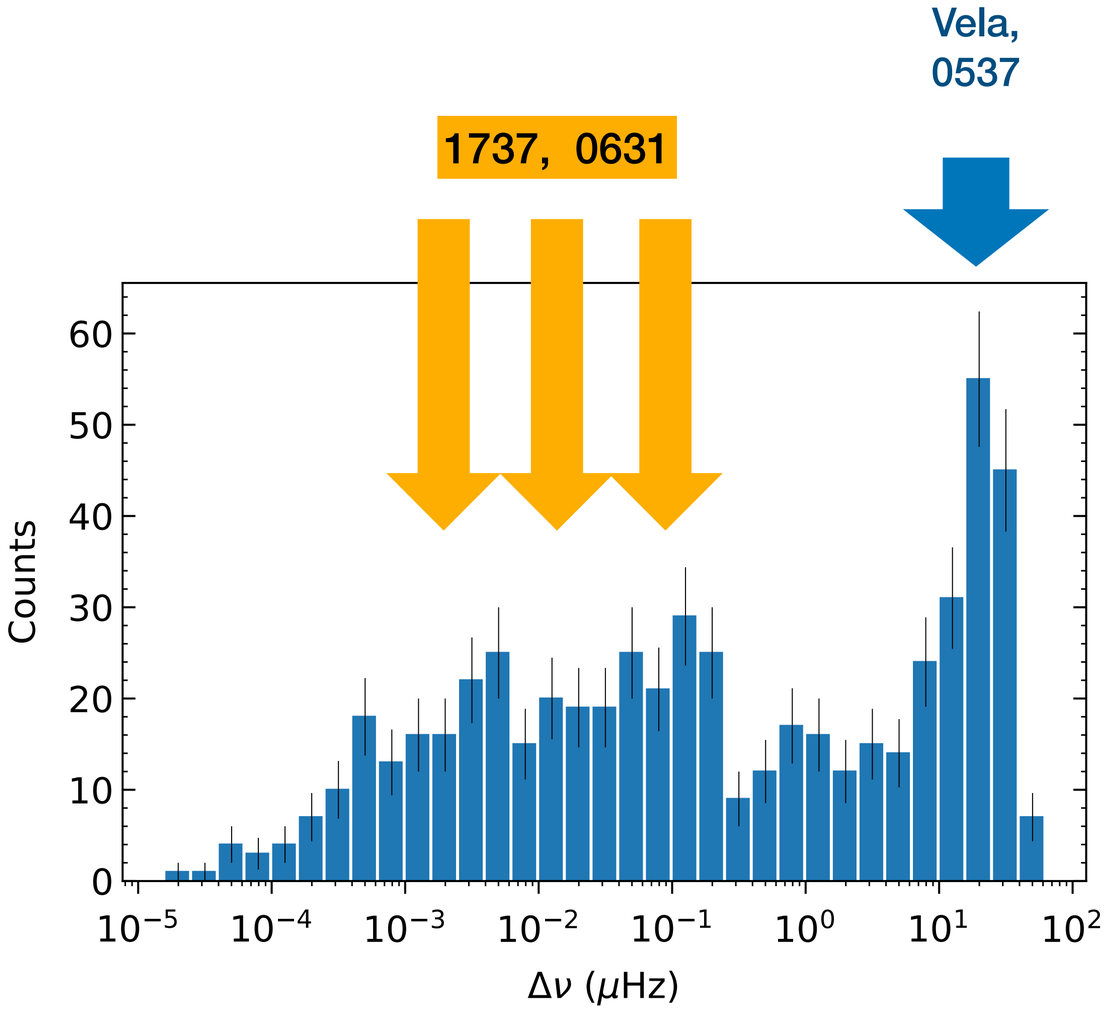
In summary

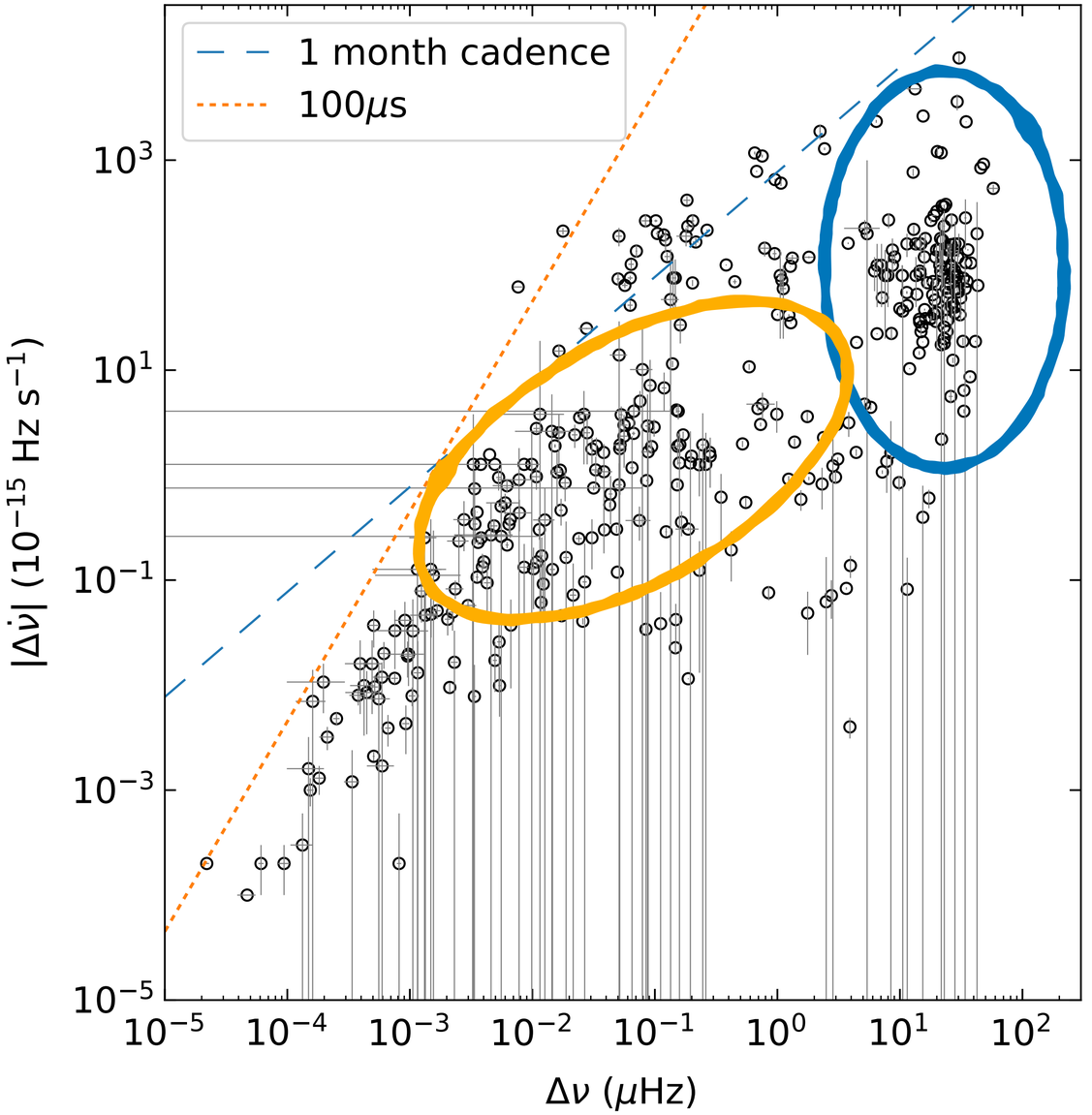
- Exponential (poissonian) waiting times
- Power-law sizes

- Characteristic times between glitches
- Characteristic glitch sizes



Tendency: *Gaussian* glitches are the largest.

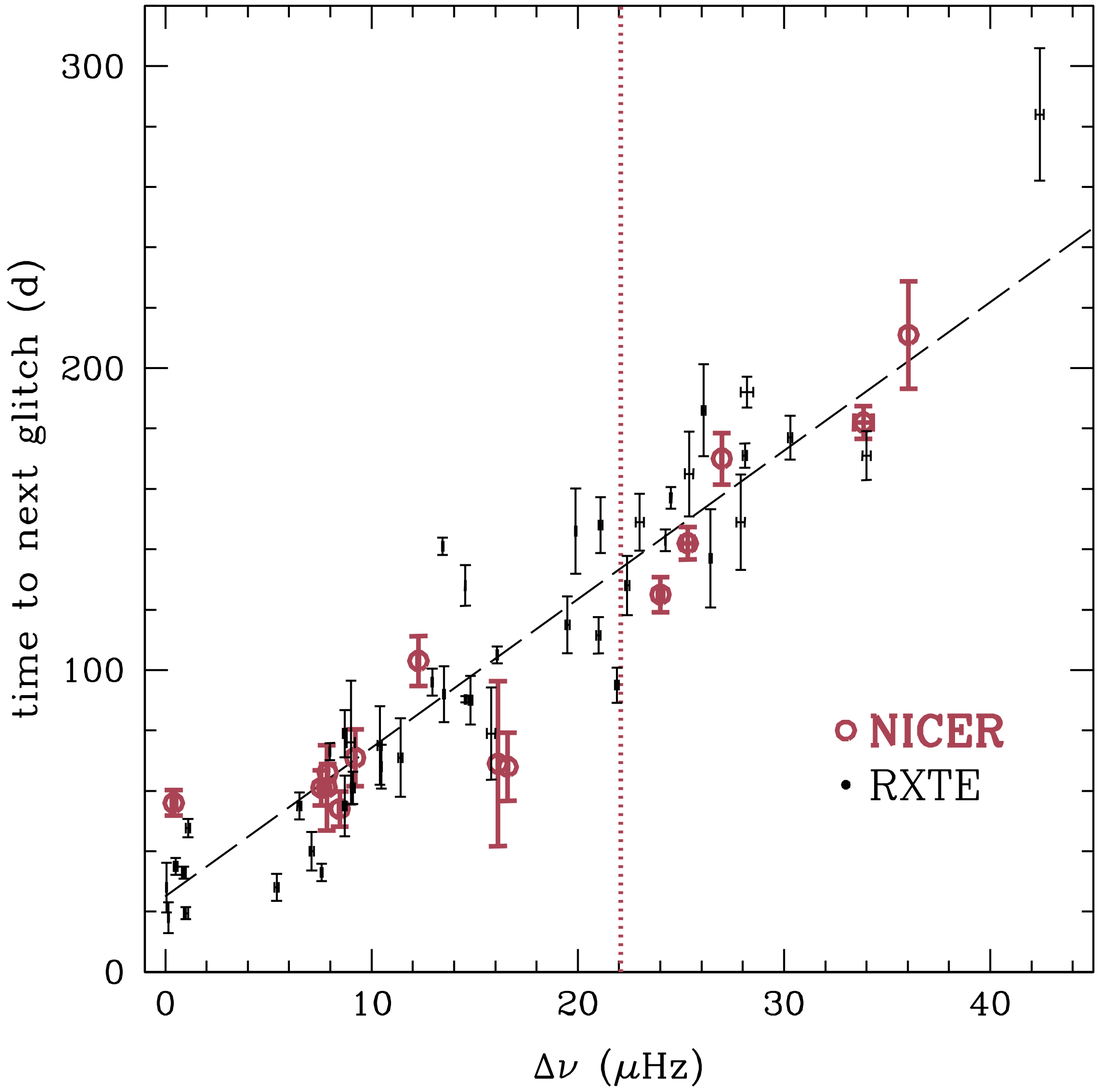




PSR J0537−6910

Gaussian glitches

- Size of glitches determines time to the next glitch.
- Suggest that **glitches happen once a critical threshold is reached**. Departure from that threshold is controlled by the glitch size. [Antonopoulou+2018]
- Threshold could be rotational velocity lag between *glitching superfluid* and rest of the star.



Ho et al. (2020, 2022)

See also: Middleditch+06
Antonopoulou+18
Ferdman+18

Simple model for J0537

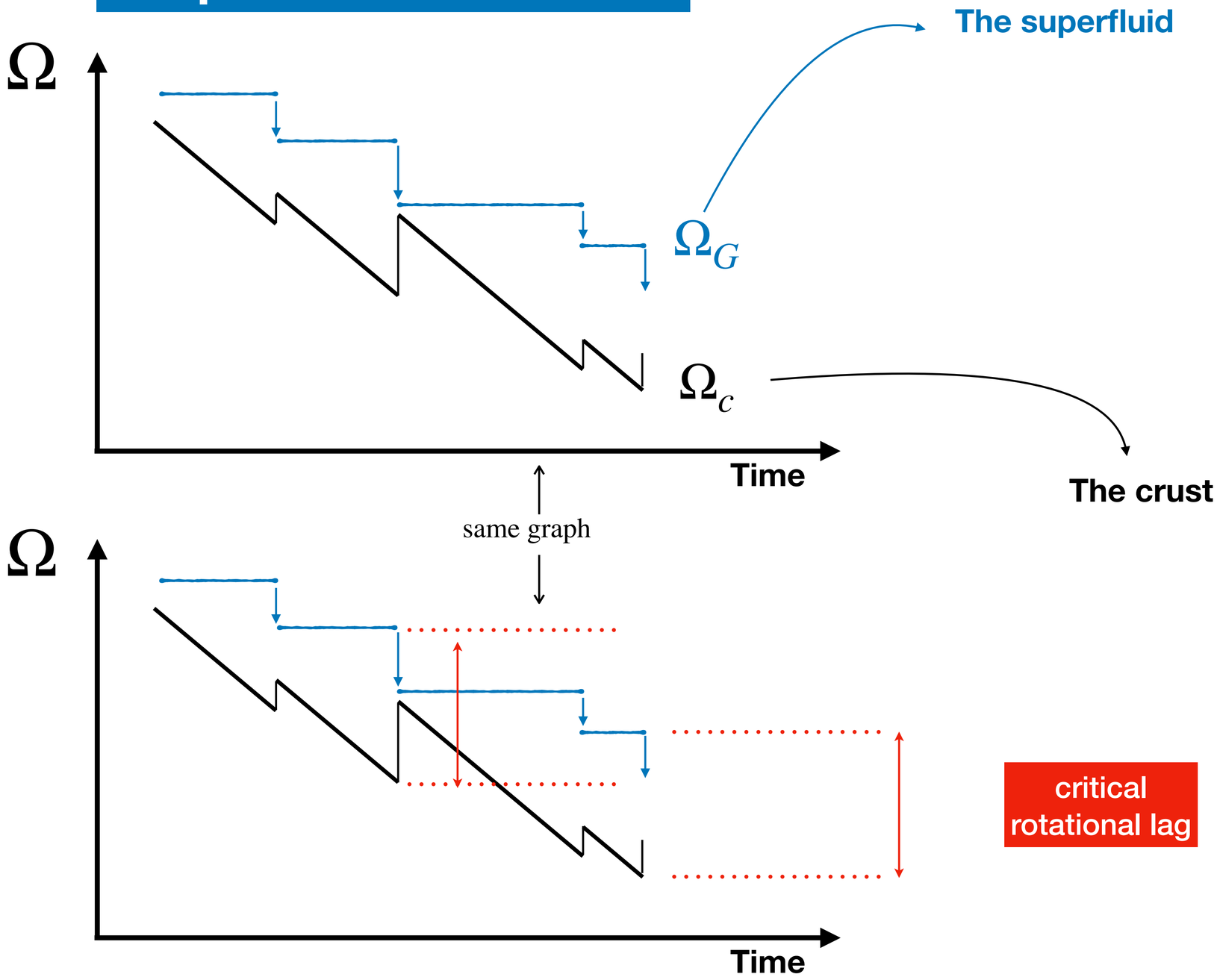
- From the RXTE data for 0537, we could infer that

  (1) Rotational lag is not reduced completely at glitches.

  (2) The moment of inertia of ***G*** is at least 0.8% of the moment of inertia of ***c***.

  (3) Maximum lag is at least 1.7 deg/s.

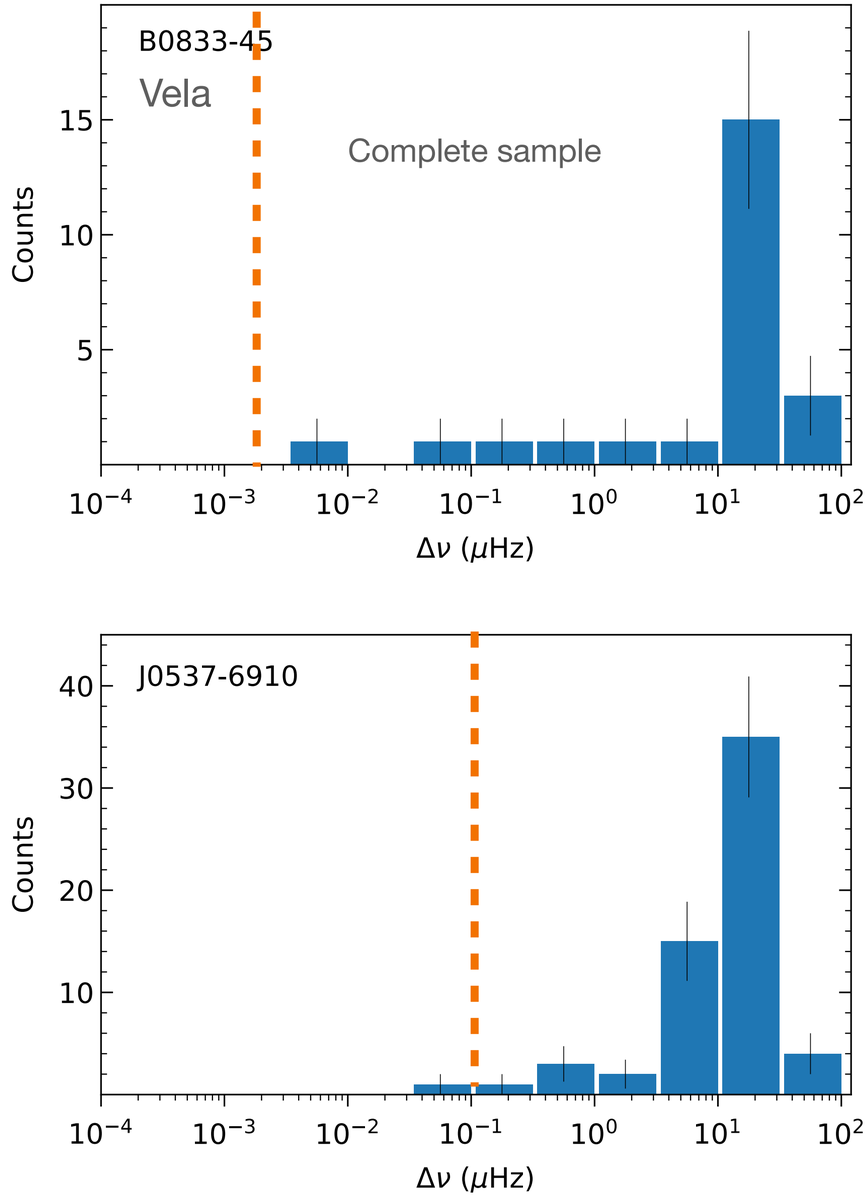
  Antonopoulou+2018



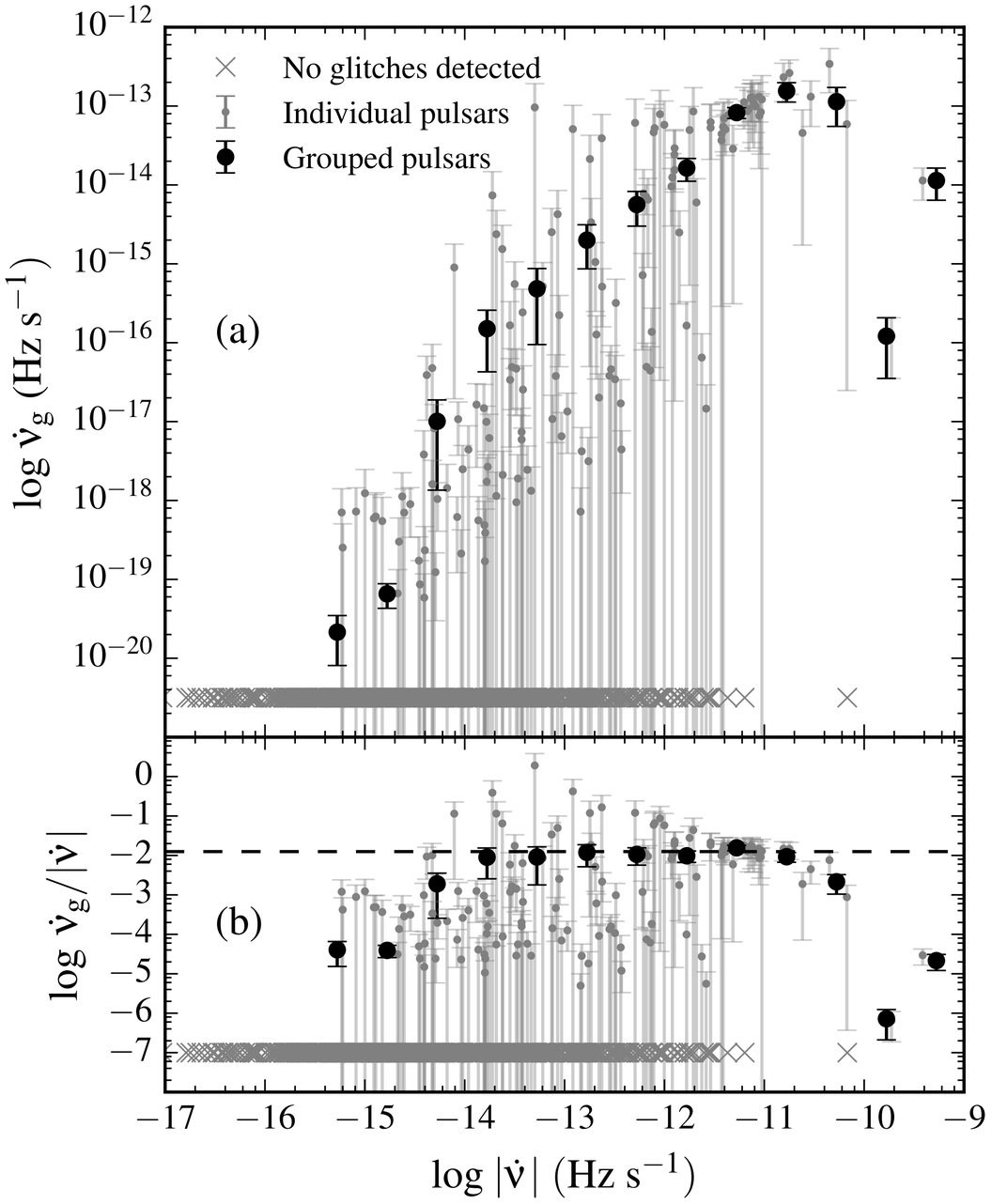
The Vela pulsar

Gaussian glitches

- There may be a hint for the correlation, present only for large (> 9 μHz) glitches. However, this is still speculative [Fuentes+2019].
- Low probability for small glitches confirmed: rate of events under 10 μHz is 4 times lower than for larger ones [Espinoza+2021].



Fuentes+2017



Integrated **glitch activity**

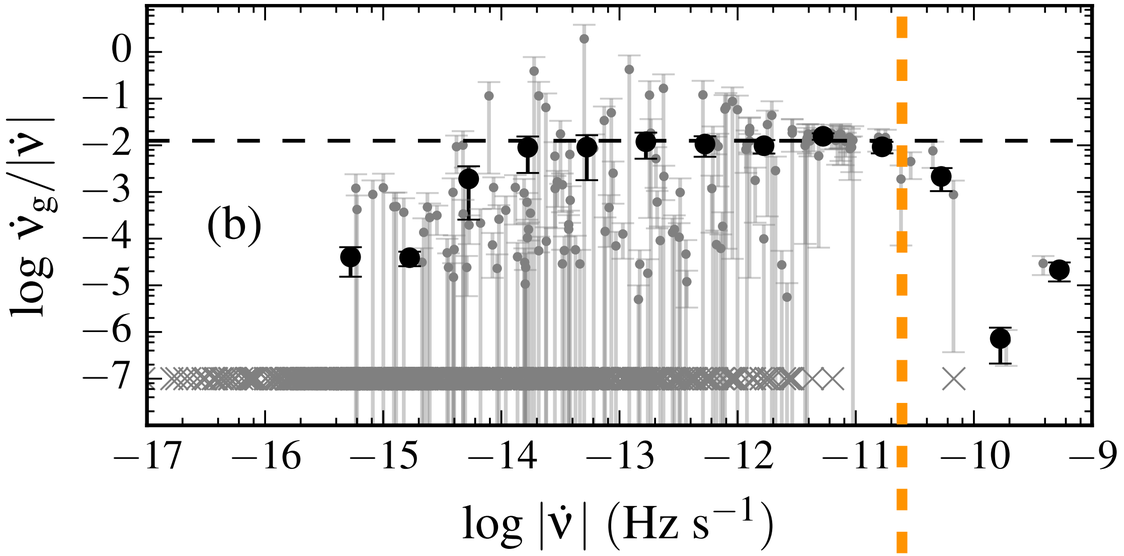
$$\dot{\nu}_{\rm g} = \frac{\sum_i \sum_j \Delta\nu_{ij}}{\sum_k T_k}$$

1. Separate known pulsars in bins
2. In a given bin: add spin-up of all glitches and divide by total observing time of all pulsars known in that bin [Lyne+2000].

1.2(1)%

Regime fails at both extremes

Related to fraction of superfluid causing glitches



1.2(1)%

Regime fails at both extremes

Low spin-down pulsars have not been observed long enough to see large glitches.

High spin-down pulsars do not follow general trend (e.g. Crab).

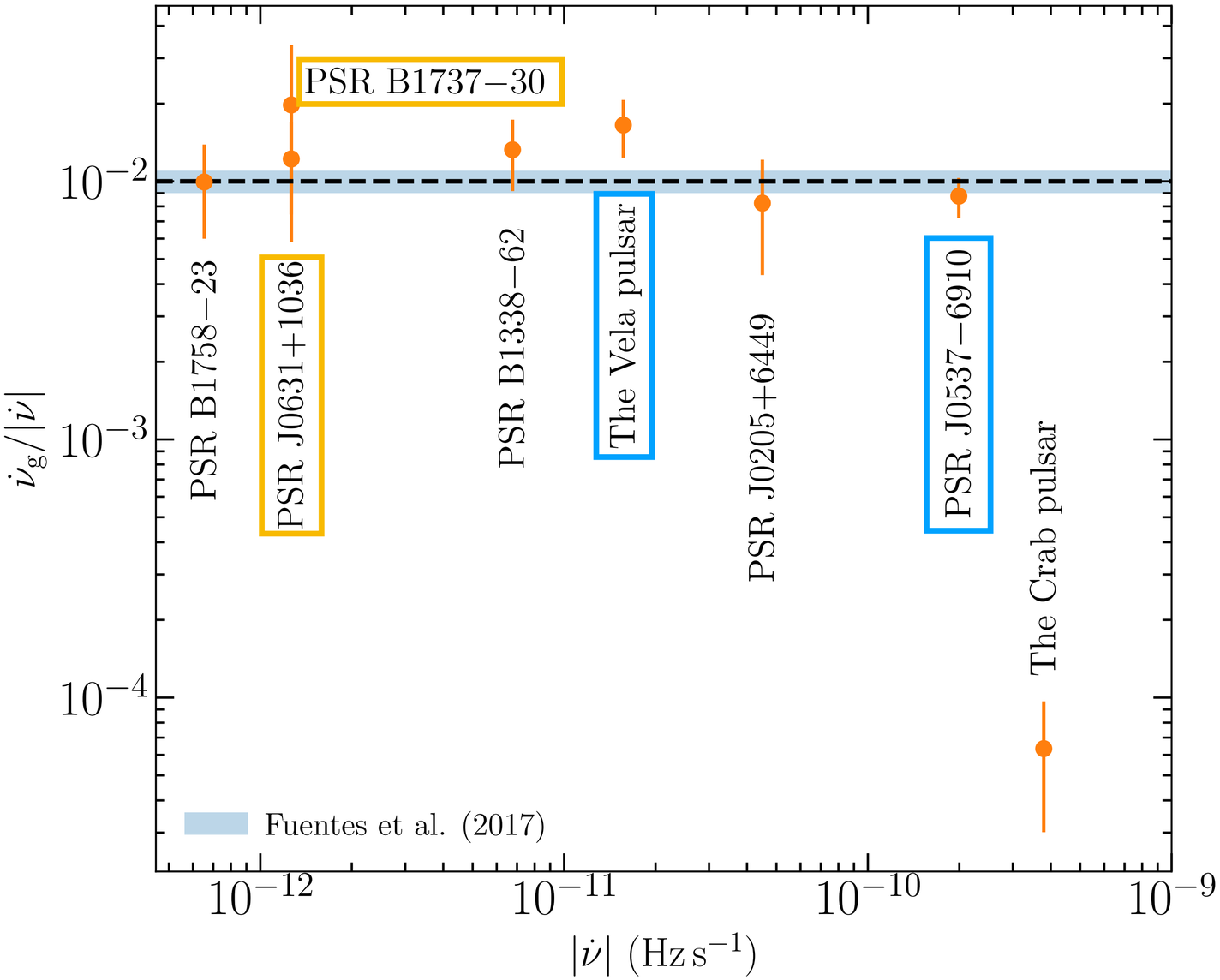
Cannot rule out that <u>all</u> these pulsars follow the general trend

Fuentes+2017

The individual activity of the 8 pulsars is what we expect, given their spin-down rate.

Thus, glitches tap a similar *size* superfluid in all pulsars,
but each pulsar decides how to use it

The 8 pulsars with 10+ detected glitches



Fuentes+2019

in other words,

the liberation of stress remains
at ~1% of the spin-down rate
regardless of the glitch sizes,
how they distribute, and
the waiting times between glitches.

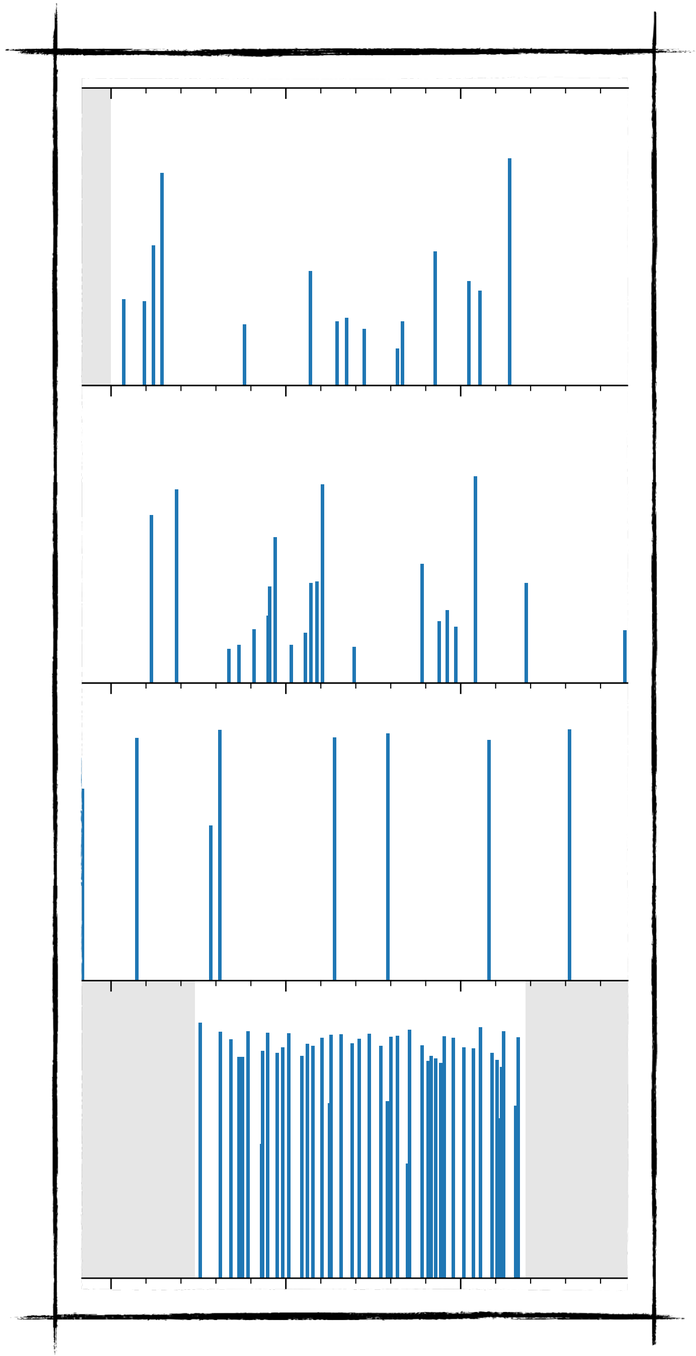
Individual glitch activities [%]

PSR	$\dot{\nu}_{\rm g}/\dot{\nu}$	
B0531+21	0.005	
J0537-6910	0.9	←
J0631+1036	2.4	←
B0833-45	2.1	←
B1338-62	1.3	
B1737-30	1.3	←
B1758-23	1.1	

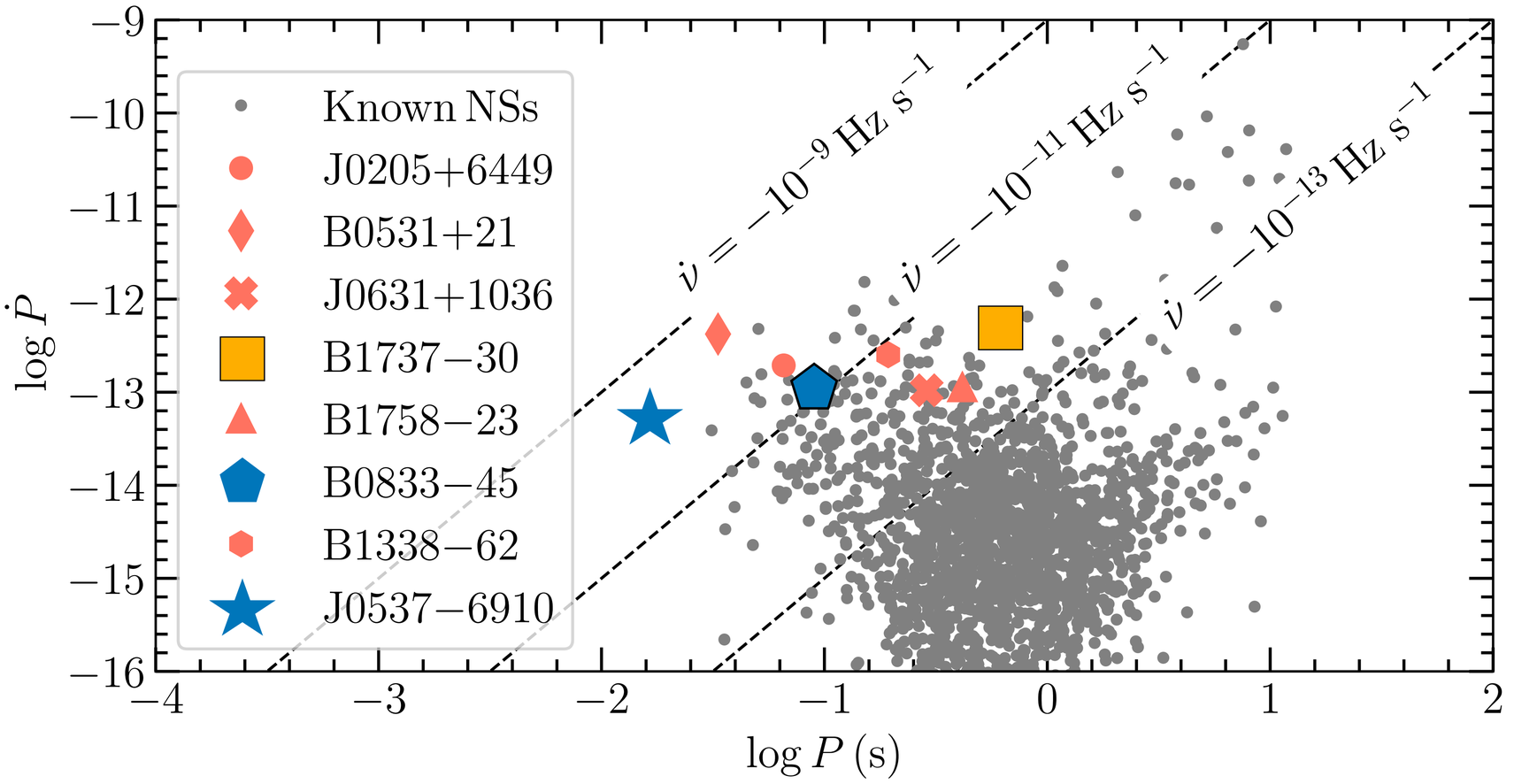
Conclusions /some thoughts

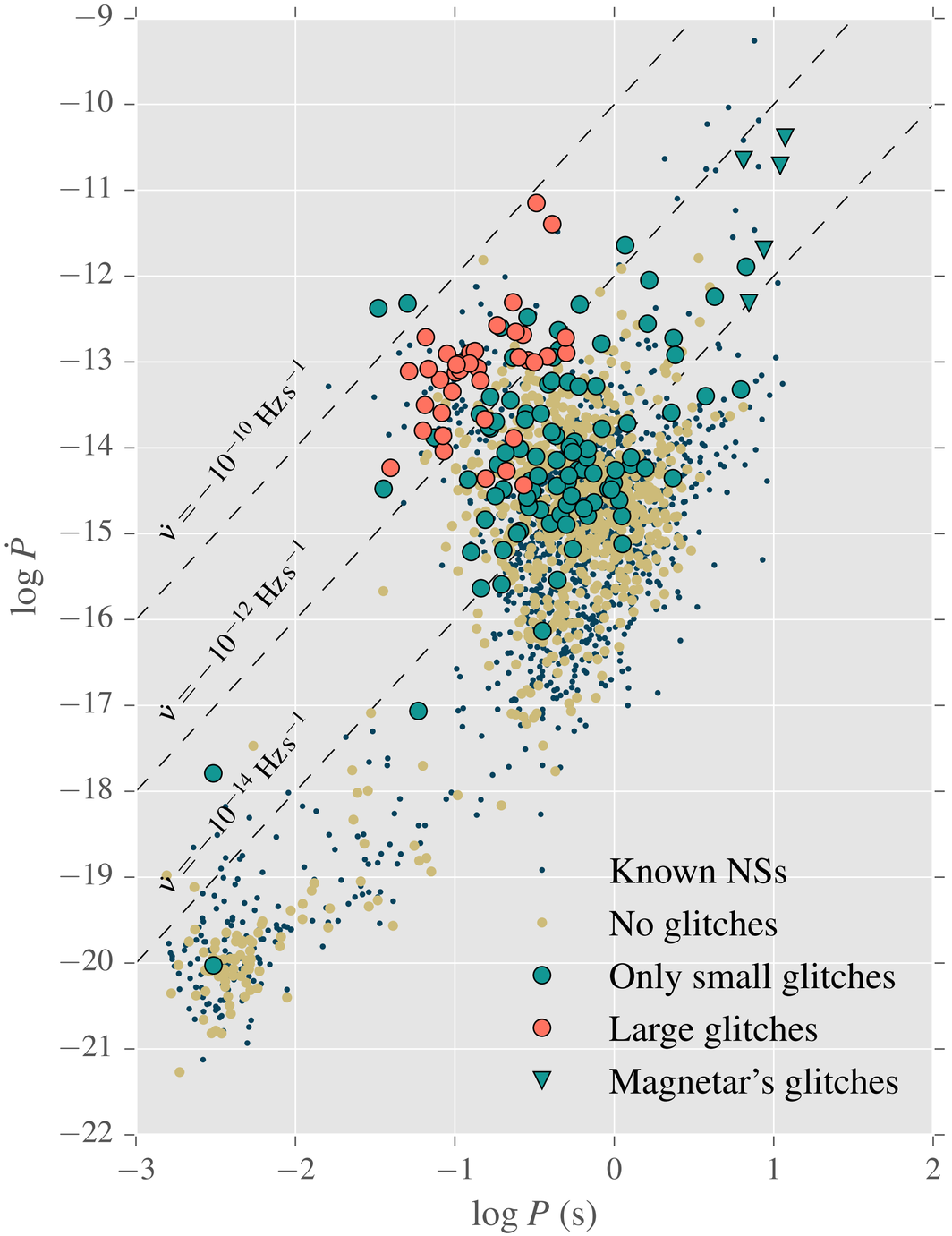
Two glitching styles

- Could mass differences account for the different behaviours? The fact that $\dot{\nu}_{\mathrm{g}}/\dot{\nu} \sim 0.01$ must be considered.
- Temperature differences?
- Evolution: Will Vela's glitching style turn into B1737-30's style?
- A different trigger mechanism: Perhaps something triggers glitches in B1737-30 before larger glitches can happen. / Something which is not active (or has no chances to be triggered) in Vela or J0537-6910.



Thank you !


Known NSs
J0205+6449
B0531+21
J0631+1036
B1737−30
B1758−23
B0833−45
B1338−62
J0537−6910
$\dot{\nu} = -10^{-9}$ Hz s^{-1}
$\dot{\nu} = -10^{-11}$ Hz s^{-1}
$\dot{\nu} = -10^{-13}$ Hz s^{-1}
$\log \dot{P}$
$\log P$ (s)
−9
−10
−11
−12
−13
−14
−15
−16
−4
−3
−2
−1
0
1
2


−9
−10
−11
−12
−13
−14
−15
−16
−17
−18
−19
−20
−21
−22
log $\dot{P}$
−3
−2
−1
0
1
2
log P (s)
$\dot{\nu} = -10^{-10}$ Hz s^{-1}
$\dot{\nu} = -10^{-12}$ Hz s^{-1}
$\dot{\nu} = -10^{-14}$ Hz s^{-1}
Known NSs
No glitches
Only small glitches
Large glitches
Magnetar's glitches