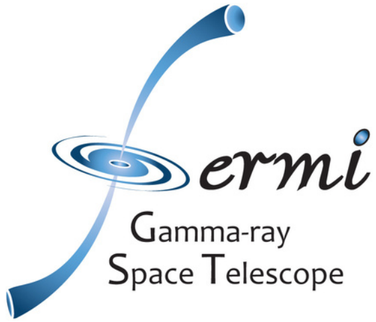

GAMMA-RAY PULSAR GLITCHES: A STUDY OF VARIABILITY IN FERMI-LAT DATA

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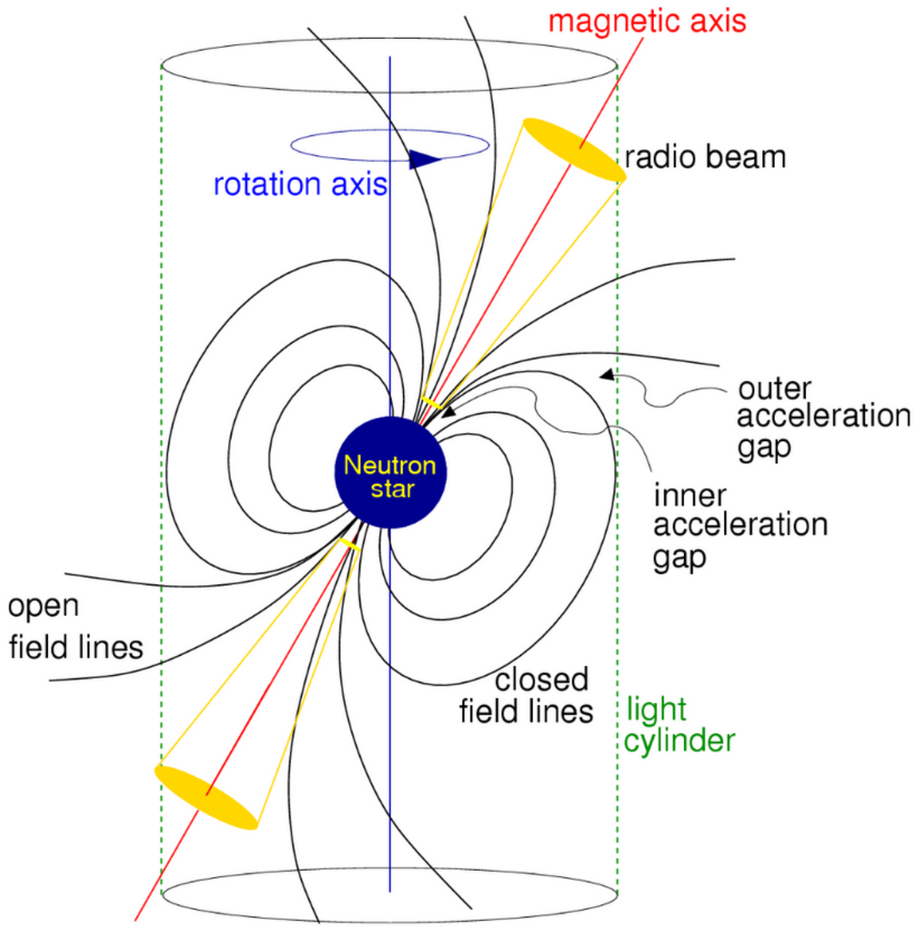
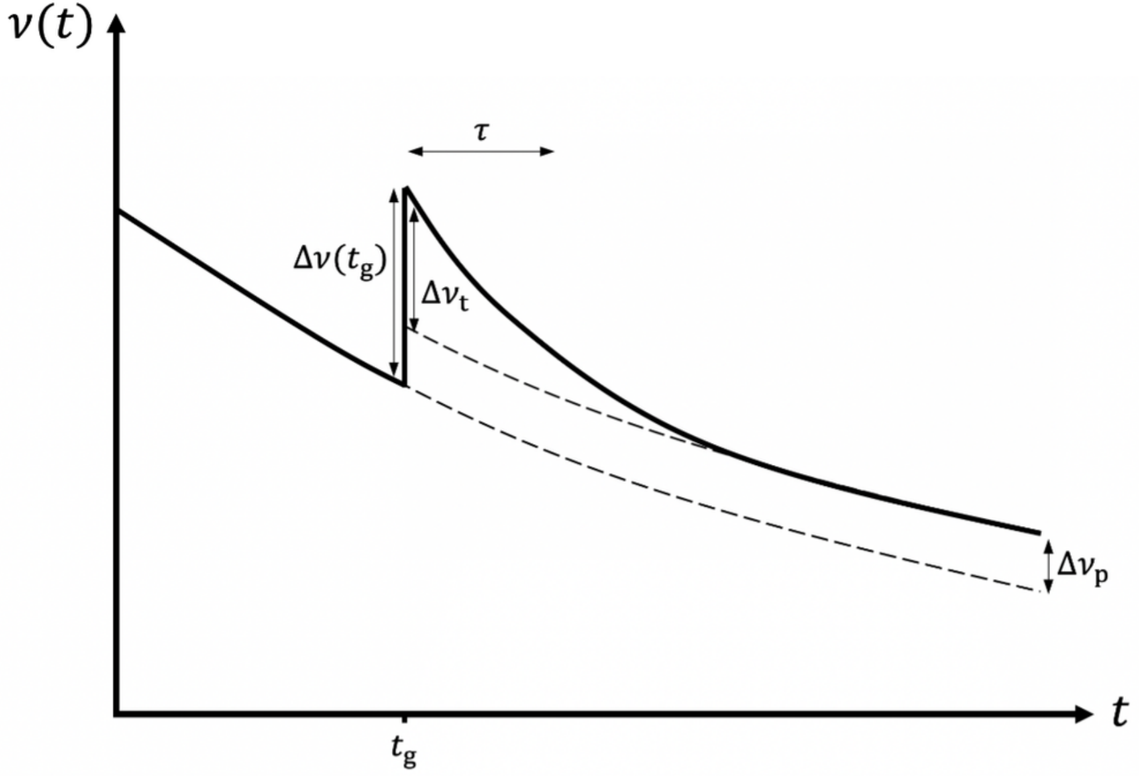
WHAT IS A PULSAR?



Credits: Lyne & Graham-Smith, 2012.

- Highly magnetized and rapidly rotating neutron star.
- **Emitting periodic signals** across the whole electromagnetic spectrum.
- Among the most stable rotators known in the universe.
- **Slowing down gradually** because of the conversion of rotational energy into electromagnetic radiation, pulsar wind and gravitational waves.
- Their γ-rays are observed with LAT.

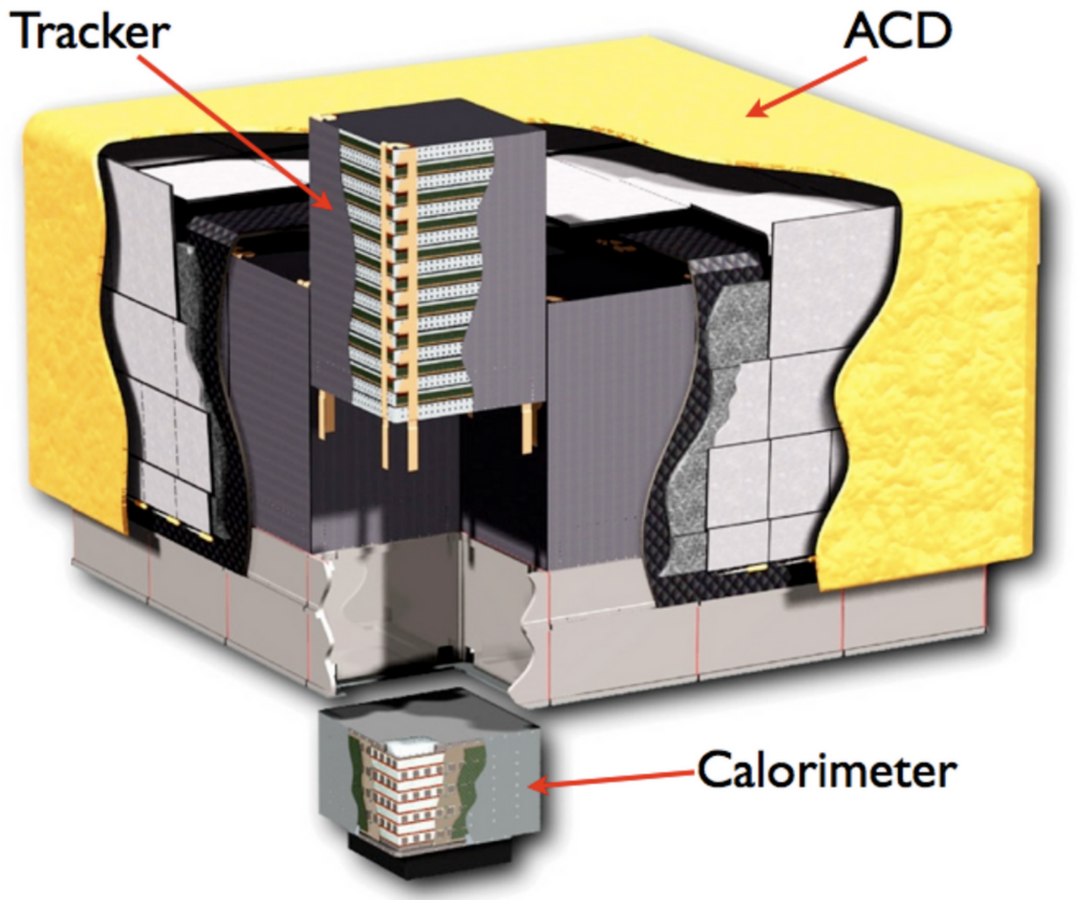
PULSAR GLITCHES



Credits: Yim & Jones, 2020.

- A glitch is a **discontinuous step in rotation frequency**.
- Followed by an exponential recovery.
- Gitches have been attributed to a variety of mechanisms.
- Two main interpretations:
  - **starquakes** occurring in the star crust (e.g. Rencoret et al., 2021);
  - **pinned vorticity** in the superfluid core (e.g. Sourie et al., 2020).

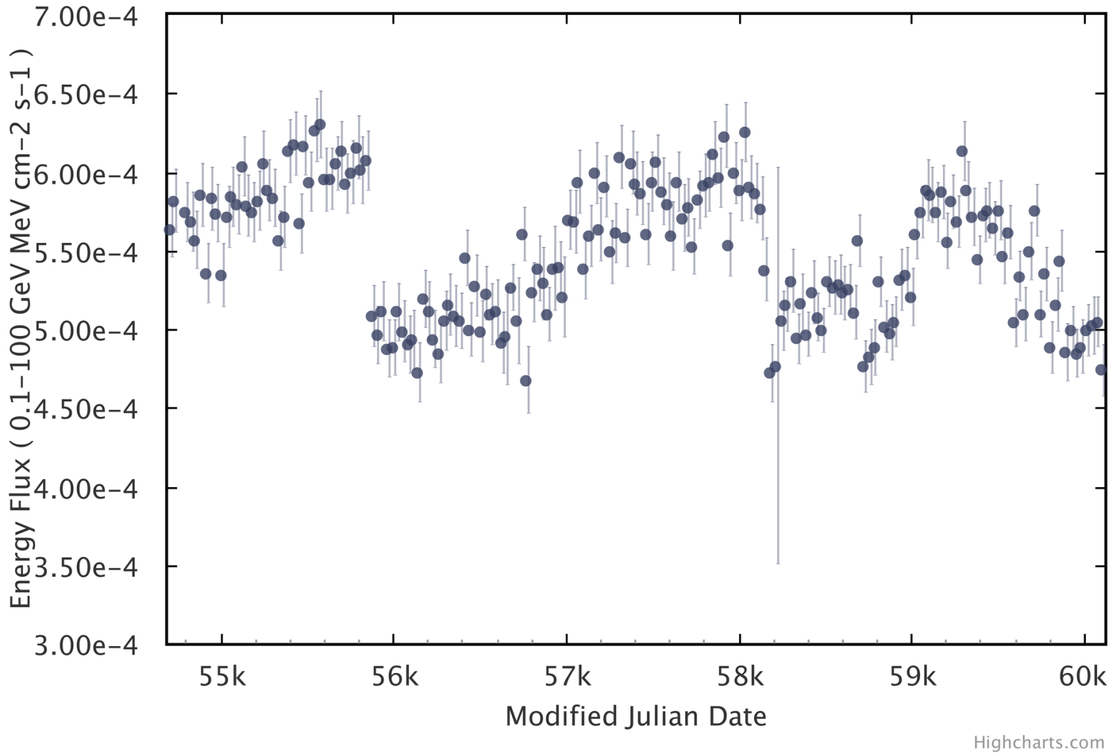
LARGE AREA TELESCOPE (LAT)



Credits: Atwood et al., 2007.

- Fermi Gamma-ray Space Telescope.
- Launched by NASA on June 11, 2008.
- **Pair conversion** telescope.
- Detect photons in an energy range **from 20 MeV to over 300 GeV**.
- Field of view 2.4 steradian (20% sky).
- Covers the **entire sky** in 3 hours.
- Measures of **time**, **energy** and **direction** of incident photons.
- Third LAT Pulsar Catalog (3PC):
  - **294 pulsar**;
  - **54 glitching pulsars**;
  - **128 glitches**.

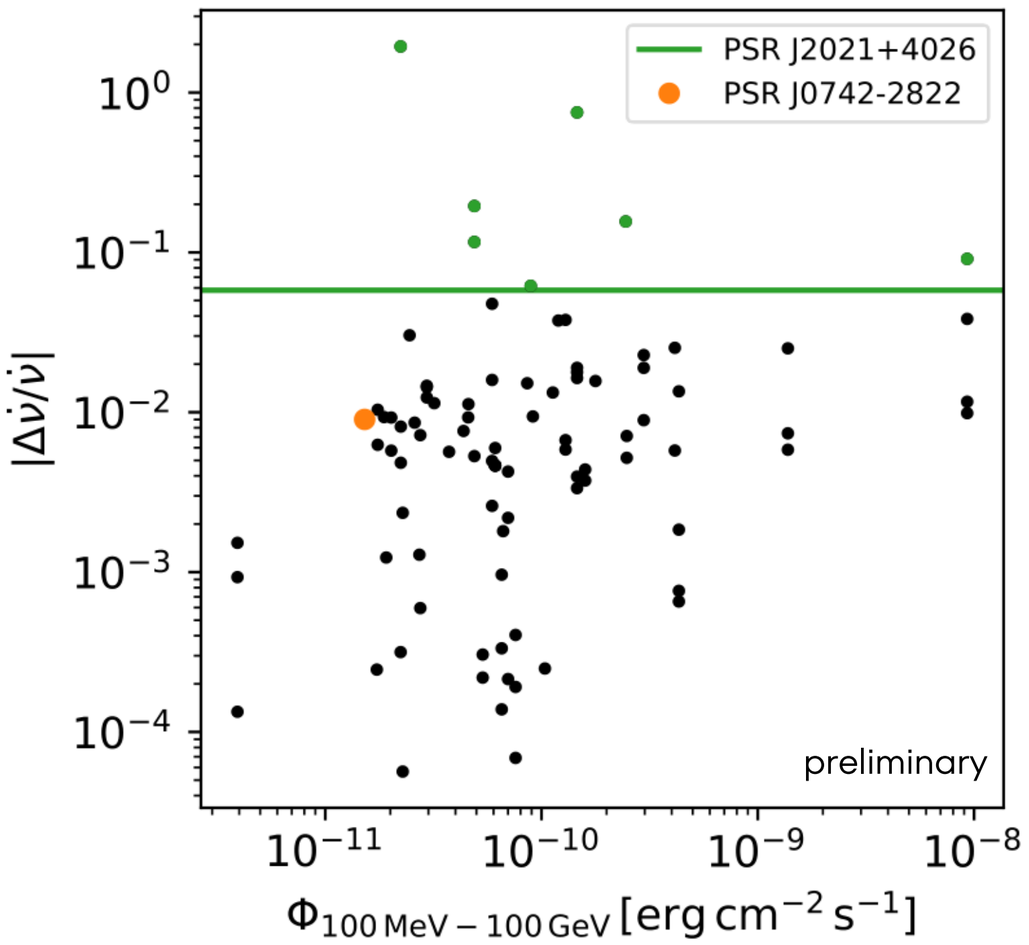
VARIABLE GAMMA-RAY PULSARS



Credits: Fermi-LAT Light Curve Repository.

- PSR J2021+4026 variability was **first discovered by LAT**.
- First and only pulsar with variable γ-ray emission.
- In 2011, **flux dropped** by (17.6 ± 1.7)%, while **rotational frequency derivative increased** by (5.8 ± 0.9)% (Allafort et al., 2013) followed by a recovery.
- To date, there is **no pulsar emission model capable of explaining the variability** (Philippov & Kramer, 2022).

PULSAR SAMPLE (1)



- We **search for similar variability** in 3PC glitching pulsars.
- We selected a **subset** of glitches:
  - **7 glitches** with relative rotational frequency derivative jump larger or comparable to 5.8%.
  - **2 glitches** in a switching radio pulsar with LAT counterpart (i.e., PSR J0742-2822), whose rotational frequency derivative changes by 0.66%, while the radio pulse full widths at 75% changes by 20% (Lyne et al., 2010).

PULSAR SAMPLE (2)

PSR [J2000]	ν [Hz]	$\dot{\nu}\,[-10^{-11}]$	τ_c [kyr]	$B_S\,[10^{12}\,G]$	$\dot{E}_{rot}\,[-10^{37}\,erg\,s^{-1}]$	GLEP[1] [MJD]	$\Delta\nu/\nu\,[10^{-9}]$	$\Delta\dot{\nu}/\dot{\nu}\,[10^{-3}]$
J0835-4510[2]	11.19	1.55	11.3	3.38	0.69	56555	3091.21	91.09
J1023-5746	8.97	3.05	4.6	6.62	1.1	55024	3136.47	−751.35
J1028-5819	10.94	0.19	89.87	1.23	0.083	57853	2342.98	156.18
J1341-6220	5.17	0.68	12.1	7.08	0.14	55042	−724.87	−1942.17
J1833-1034	16.15	5.27	4.85	3.58	3.4	55156	−48.00	−61.74
J2111+4606	6.34	0.65	17.5	4.81	0.14	54750	−442.26	−116.22
J2111+4606	-	-	-	-	-	55668	1376.77	195.1
J0742-2822[3]	6.00	0.06	158.81	1.69	0.014	55020	103.72	9.02
J0742-2822	-	-	-	-	-	56727	2.94	0.00

[1]glitch epoch
[2]Vela Pulsar
[3]switching radio pulsar

SPECTRAL VARIABILITY

PSR [J2000]	n_{glitch}	σ_{N_0}	σ_{Γ_S}
J0835-4510	I	0.1	0
J1023-5746	I	0.1	0
J1028-5819	I	0.1	0
J1341-6220	I	2	1
J1833-1034	I	0.5	2
J2111+4606	I	1	0.6
J2111+4606	II	0.3	1
J0742-2822	I	0.5	0.3
J0742-2822	II	0.1	0.1

- **Summed** and **weighted** likelihood.
- We prepare different sets of data and include as separated components.
- Event types are based on the **quality of the reconstructed direction**.
- Science Tools by LAT Collaboration integrated in our Python package.
- Analysis on the batch farm at SLAC.
- Pulsar spectral model: $dN/dE \propto N_0\, E^{-\Gamma_S}$.
- **Spectral parameters** pre/post-glitch variations in units of standard deviations.
- **No significant variability** detected.

PULSE PROFILE VARIABILITY

PSR [J2000]	n_{glitch}	$\sigma_{\delta_{\text{P1}}}$	$\sigma_{\delta_{\text{P2}}}$	$\sigma_{\Delta_{\text{P1-P2}}}$	$\sigma_{\text{P1/P2}}$
J0835-4510	I	-	-	-	-
J1023-5746	I	1.2	0.5	0	0.4
J1028-5819	I	0	0.8	1	0
J1341-6220	I	-	-	-	-
J1833-1034	I	0	0	0	0
J2111+4606	I	-	-	-	-
J2111+4606	II	0.2	1	0.7	2
J0742-2822	I	-	-	-	-
J0742-2822	II	-	-	-	-

- Best fit with the high-precision Python pulsar timing data analysis package PINT (Luo et al., 2019).
- The obtained pulse profiles always show **two peaks** (P1 and P2).
- Pre/post-glitch variations in units of standard deviations for:
  - **peaks' widths**;
  - **displacement of P2 from P1**;
  - **ratio between peak amplitudes**.
- For some intervals, photons were not enough to distinguish the pulses.
- **No significant variability** detected.

SUMMARY AND OUTLOOK

- There are **294 pulsars**, **54 glitching pulsars** and **128 glitches** in LAT data.
- This is the first search of γ-ray **emission variability correlated with glitches**.
- We considered a **subset of glitches** that we consider particularly promising.
- We did not find any significant variability, thus **PSR J2021+4026 remains unique**.
- **No model** is currently able to accurately predict the γ-ray pulsar state changes.
- If **similar variable pulsars** were found, further advancements could be achieved.
- This variability analysis can be applied to **all other glitches** too.

Thank you for listening!

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