Timing and Characterisation of Pulsar Glitches with Fermi LAT

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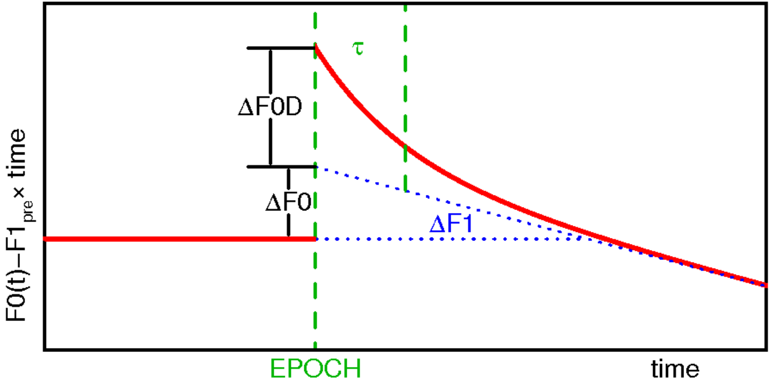
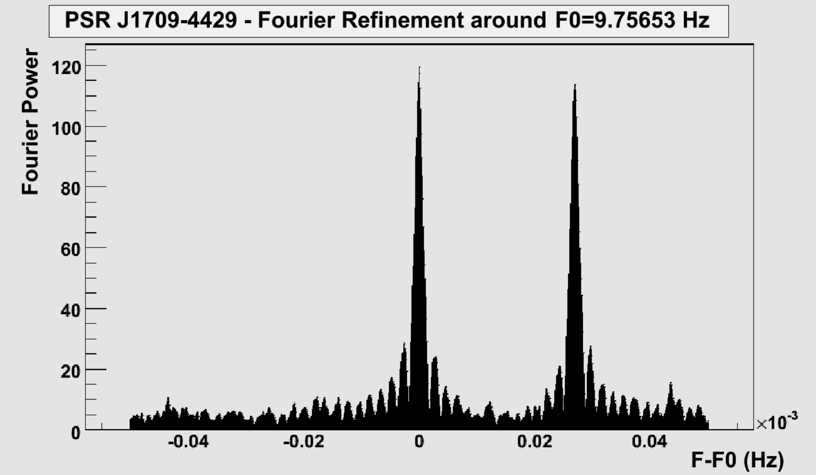
1. Introduction
   - Signatures of a glitch
   - Glitches in LAT data
2. Measuring Glitch Parameters with the LAT
   - Finding glitches with the LAT
   - Reading the frequency evolution plot
   - Reading the profile evolution plot
3. Some Examples of LAT-detected Glitches
   - Radio-faint and radio-quiet pulsars
   - The two glitches of PSR J0007+7303 (CTA-1)
   - Search for short-term variability around the Vela glitch
   - Search for pulse profile variability around the Vela glitch
4. The Sample of LAT-detected Glitches in 32 Months
   - LAT pulsars and glitches
   - Glitch size distribution
5. Conclusion

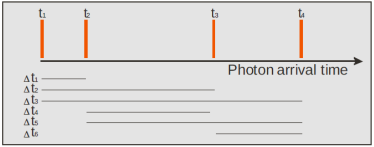
1. Pulsars are very stable clocks (F0, F1)
2. Two types of deviation from a linear spindown:
   - smooth evolution of F0 and F1 (timing noise)
   - abrupt changes in F0 and F1 (glitches)
3. Three timing signatures of a glitch:
   - sudden increase in the spin rate (F0)
   - sudden increase (normally) in the spin down rate (-F1)
   - transient phase of exponential recovery (from minutes to weeks)



1. Glitches are historically mainly detected in radio
2. Glitches are mainly seen in young and energetic pulsars
3. The LAT, continuously monitoring dozens of young and energetic pulsars, has the capability of detecting glitches from γ rays only

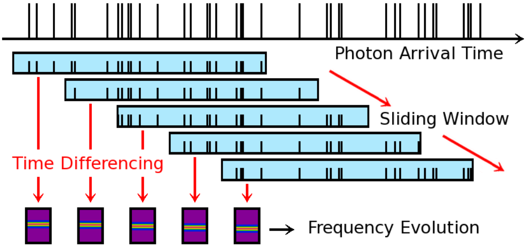


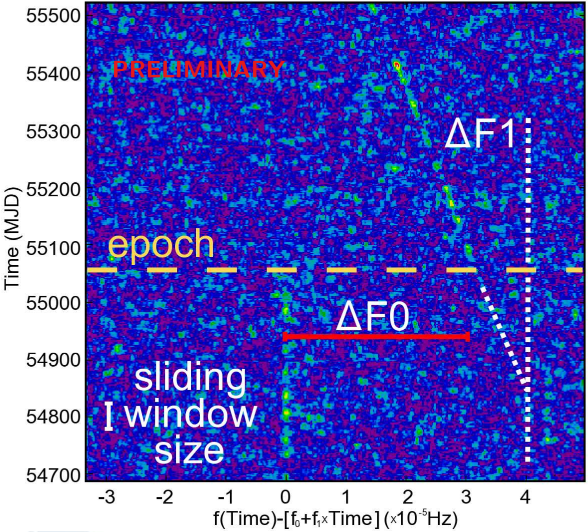
1. The time-differencing technique (Atwood et al 2006):
   - FFT over time differences instead of event times
   - less intensive on cpu and memory (smaller FFTs)
   - the coherence requirements are greatly reduced



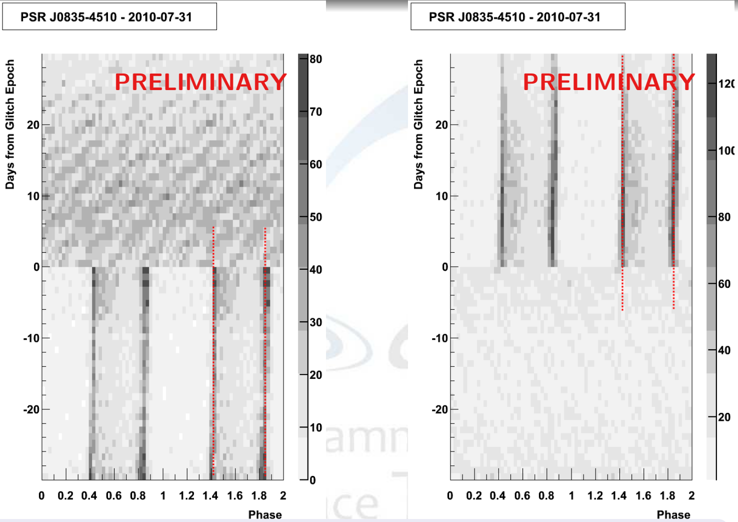
Credit: M. Ziegler

2. Applying this technique to a sliding time window, we can follow the evolution of the pulsation frequency, when detectable

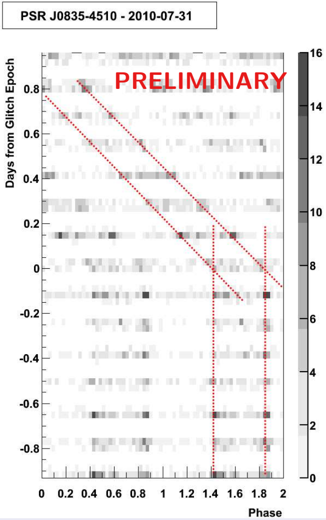


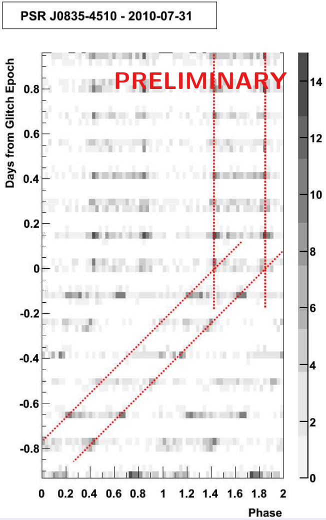


Frequency evolution plot of PSR J1023-5746 (F0=8.97 Hz, F1=-3.09e-11Hz)
Glitch (Jul 29th 2009): ΔF0=3.2e-5 Hz ; ΔF1=-3.0e-13 Hz/s

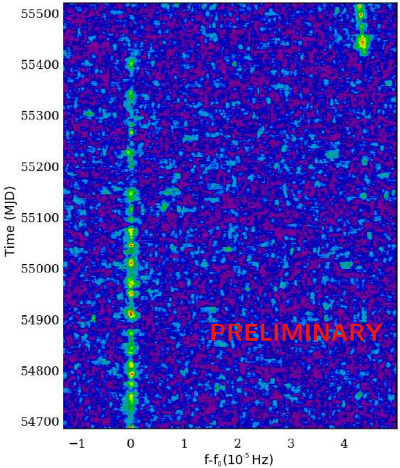


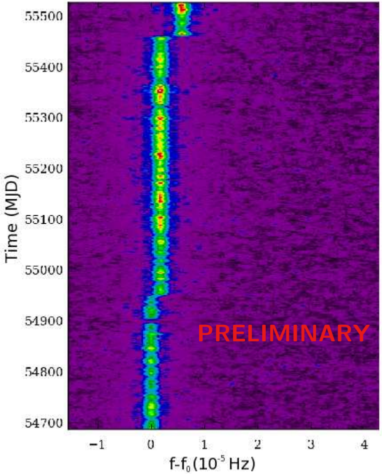
- We get 2 distinct timing solutions: before and after the glitch (Ray et al. 2011)
- We fold the event times over the two ephemerides obtained in each of the periods
- Pulse profile evolution for PSR J0835-4510 (Vela) around the glitch (Jul 31th 2010)





- Zooming in, where the signal gets lost, we see when and how the solutions join
- The epoch we get is very precise: $MET\ 302297026 \pm 600 = MJD\ 55408.808 \pm 0.007$
- This estimate agrees, within 160 sec, with the radio estimate (S.Buchner ATel #2768)

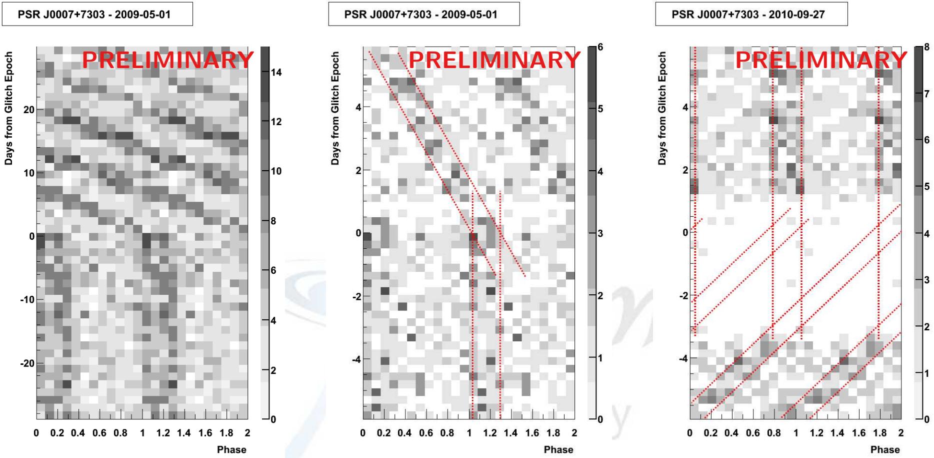




Glitch in the radio-faint PSR J1907+0602 (Aug 14th 2010)
Two glitches in the radio-quiet PSR J0007+7303 (May 1st 2009, Sep 26th 2010), associated with the SNR CTA-1 (see poster by K.Wood)

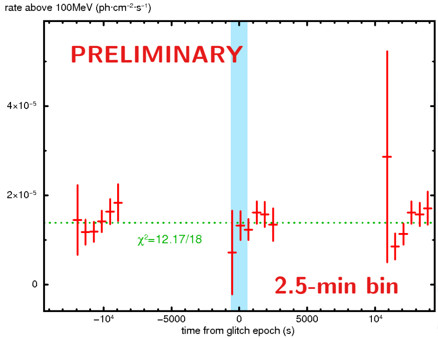
Some Examples of LAT-detected Glitches

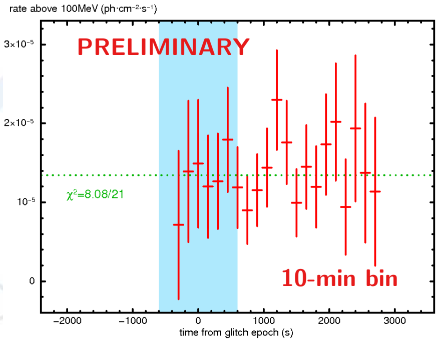
The two glitches of PSR J0007+7303



- The low statistics limit how much we can zoom in
- In the second glitch a TOO on the Crab leaves a gap in the data
- Assuming no recovery we can phase-connect with an ambiguity
- If we allow for a recovery, any time in the gap is a possible epoch

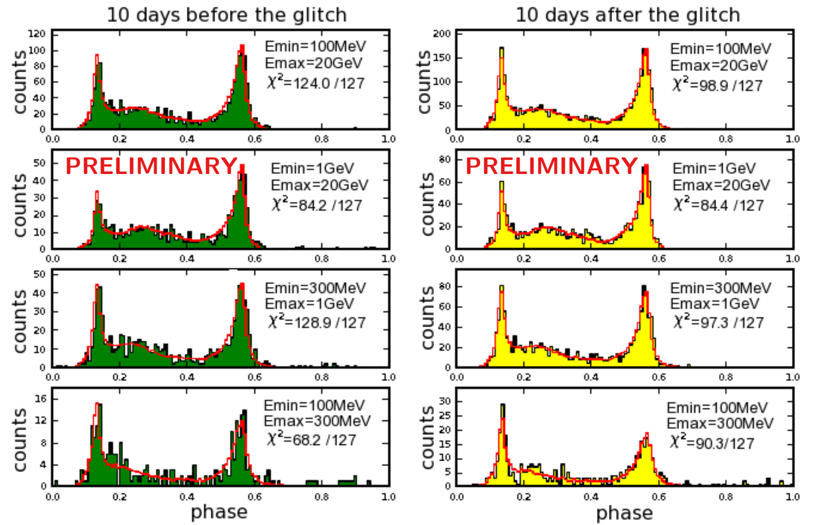
Some Examples of LAT-detected Glitches
Search for short-term variability around the Vela glitch



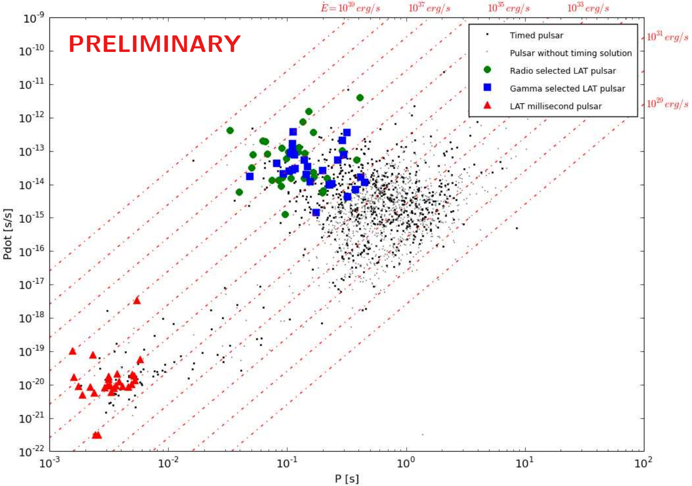


- Possible γ-ray flare associated to the 2007 glitch from Vela (Pellizzoni et al. 2009)
- Variability analysis on very short timescales using exposure-corrected aperture photometry
- No evidence of flaring activity down to 2.5 min timescale
- Marginal possibility that the glitch happened before the pulsar entered the LAT FoV.

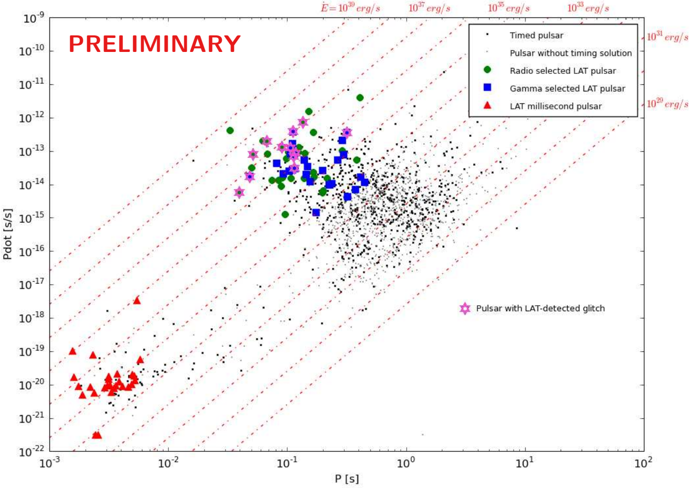
Some Examples of LAT-detected Glitches
Search for pulse profile variability around the Vela glitch



- We tested for changes in the pulse profile across the glitch ($\pm$10 days)
- We repeated the analysis selecting photons in several energy bands
- Kolmogorov-Smirnov and χ^2 tests do not show evidence of change



- This plot (from the talk of D.Smith) uses data from:
  - The ATNF catalog (http://www.atnf.csiro.au/people/pulsar/psrcat/)
  - Espinoza et al. 2011 (http://www.jb.man.ac.uk/pulsar/glitches.html)



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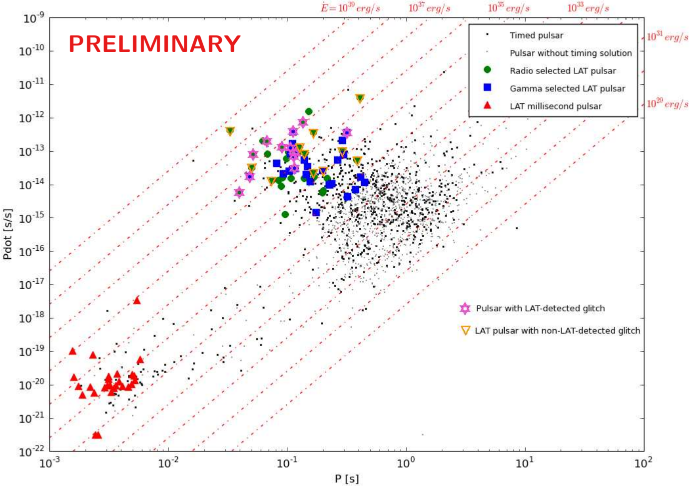

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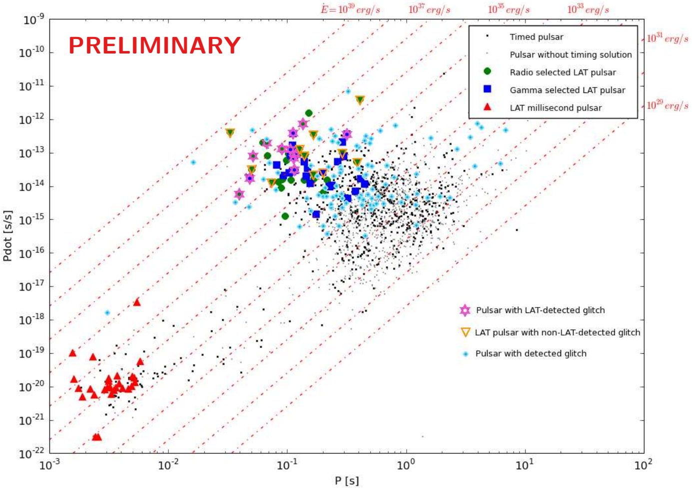

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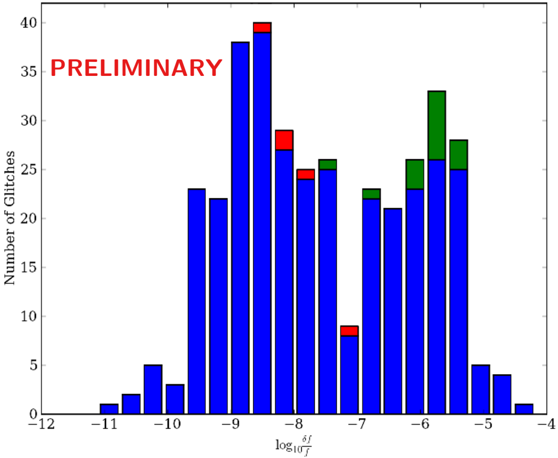

- LAT-detected glitches in green, LAT-undetected glitches in red
- Several factors determine the detectability of glitches by the LAT:
  - Lack of statistics for γ-ray faint pulsars (see poster by M.Dormody)
  - Microglitches are more difficult to distinguish from timing noise
  - Pulsars with broad peaks and strong background are hard to time

Conclusion

- The LAT, scanning the whole sky, monitors daily a large number of pulsars
- Glitches are very likely to occur in the young population of LAT pulsars
- To date, 15 glitches were detected in 13 pulsars, analyzing LAT data only
- $\simeq$ 50% of LAT-detected glitches occurred in pulsars not timed in radio
- The smallest glitch detected so far by the LAT has $\frac{\Delta F_0}{F_0} = 3.1 \times 10^{-8}$
- We use a glitch detected in Vela as a test case for an in-depth study
- The large statistics allow us to place strong constraints:
  - The epoch can be determined reliably with an uncertainty of ± 10 min
  - We estimate the size of the glitch as $\frac{\Delta F_0}{F_0} = 1.92 \times 10^{-6}$
  - No evidence for flares or variability in the flux down to 2.5 min timescale
  - No evidence for change in the pulse profile of the pulsar across the glitch
- A paper is in preparation collecting all the results (M.Dormody et al.)

BACKUP SLIDES

Pulsar Name	F_0 (Hz)	F_1 (Hz/s)	$Edot$ (erg/s)	τ_{char} (kyr)	Gl.Epoch (MJD)	Gl.Size $(\frac{\Delta F_0}{F_0})$	radio
J0007+7303	3.166	-3.6e-12	4.5e35	14	54954	5.54e-7	quiet
J0007+7303	3.166	-3.6e-12	4.5e35	14	55466	1.26e-6	quiet
J0205+6449	15.21	-45e-12	2.7e37	5.4	54795	1.74e-6	loud
J0835-4510	11.19	-16e-12	7.1e36	11	55408	1.92e-6	loud
J1023-5746	8.970	-31e-12	1.1e37	4.6	55041	3.56e-6	quiet
J1124-5916	7.380	-41e-12	1.2e37	2.9	55191	3.1e-8	faint
J1413-6205	9.112	-2.3e-12	8.3e35	63	54735	1.73e-6	quiet
J1420-6048	14.66	-18e-12	1.0e37	13	55435	1.35e-6	loud
J1709-4429	9.756	-9.0e-12	3.5e36	17	54693	2.75e-6	loud
J1813-1246	20.80	-6.8e-12	5.6e36	48	55094	1.16e-6	quiet
J1907+0602	9.378	-7.6e-12	2.8e36	20	55422	4.66e-6	faint
J1952+3252	25.29	-3.7e-12	3.7e36	108	55325	1.50e-6	loud
J2021+3651	9.639	-8.9e-12	3.4e36	17	55109	2.23e-6	loud
J2229+6114	19.36	-29e-12	2.2e37	11	55130	2.05e-7	loud
J2229+6114	19.36	-29e-12	2.2e37	11	55599	1.23e-6	loud

Preliminary table from M.Dormody et al. (in prep.)